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# Compendium of Superfund Field Operations Methods

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The Compendium provides Superfund Remedial Project Managers (RPM), qulaity assurance officers, and State officials with a consolidated ready reference for all remedial field procedures at uncontrolled hazardous waste sites. It is also intended to contribute to improved consistency in field procedures among the ten EPA Regions.

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# A Compendium of Superfund Field Operations Methods

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# A Compendium of Superfund Field Operations Methods

Office of Emergency and Remedial Response
Office of Waste Programs Enforcement
U.S. Environmental Protection Agency
Washington, DC 20460

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# A GLOSSARY OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AA | atomic adsorption |
| AAM | Algal Assay Medium |
| AC | alternating current |
| ACS | American Chemical Society |
| AGI | American Geological Institute |
| API | American Petroleum Institute |
| AR | authorized requester |
| ARAR | Applicable or Relevant and Appropriate Requirements |
| ASTM | American Society for Testing and Materials |
| ATSDR | Agency for Toxic Substances and Disease Registry |
| atm | atmosphere |
| BNA | base neutral acids |
| CAA | Clean Air Act |
| CCS | Contract Compliance Screening |
| CDC | Center for Disease Control |
| CDP | common-depth-point profiling |
| CE | current electrode |
| CERCLA | Comprehensive Environmental Response, Compensation and Liability Act of 1980 (PL 96-510) |
| CERCLIS | CERCLA Information System |
| CFR | Code of Federal Regulations |
| CIR | color infrared |
| CLP | Contract Laboratory Program |
| COC | chain of custody |
| COD | Chemical Oxygen Demand |
| COE | U.S. Army Corps of Engineers |
| CRDL | Contract Required Detection Limits |
| CWA | Clean Water Act |
| d.b.h | diameter breast height |
| DC | direct current |
| DO | dissolved oxygen |
| DOJ | Department of Justice |
| DOT | Department of Transportation |
| DQO | data quality objectives |
| DRI | Direct Reading Instrument |
| ECD | electron capture detector |
| EDMI | electronic distance meter instrument |
| Eh | oxygen-reduction potential |
| EM | electromagnetic |
| EMSLLV | Environmental Monitoring System Laboratory-Las Vegas |
| EOS | equivalent opening size |
| EP | toxicity--extraction procedure toxicity |
| EPA | Environmental Protection Agency |
| EPIC | Environmental Photographic Interpretation Center |
| ER | electrical resistivity |
| ERP | Emergency Response Plan |
| ERT | EPA Emergency Response Team |
| ERTS | Earth Resources Technology Satellite |
| EROS | Earth Resources Observation Systems |
| ESB | EPA Environmental Services Branch |
| ESD | Environmental Services Division |
| EST | Eastern Standard Time |
| eV | electron volt |
| FAA | Federal Aviation Administration |
| FIT | Field Investigation Team |
| FS | Feasibility Study |
| FSP | Field Sampling Plan |
| GC | Gas Chromatographs |
| GC/MS | Gas Chromatrography/Mass Spectrometer |

| | |
|---|---|
| **GEMS** | Graphical Exposure Modeling System |
| **gpm** | gallons per minute |
| **GPR** | Ground Penetrating Radar |
| **GSC** | a company name |
| **GT** | greater than |
| **HASP** | Health and Safety Plan (see also Site Safety Plan) |
| **HAZMAT** | Hazardous Materials Team |
| **HEP** | Habitat Evaluation Procedure |
| **HEPA** | High Efficiency Particulate Air |
| **HNU** | indicates a photoionization device |
| **HR** | heart rate |
| **HRS** | Hazard Ranking System |
| **HSCD** | EPA Headquarters Hazardous Site Control Division |
| **HSI** | habitat suitability index |
| **HSL** | Hazardous Substance List (previous term for Target Compound List) |
| **HSO** | Health and Safety Officer (see also SSC, SSHO and SSO) |
| **HSWA** | Hazardous and Solid Waste Amendments |
| **HU** | habitat unit |
| **IATA** | International Air Transport Association |
| **ICAO** | International Civil Aviation Regulations |
| **ICP** | Inductively Coupled Plasma |
| **ICS** | Incident Command System |
| **ID** | inside diameter |
| **IDL** | Instrument Detection Limit |
| **IDLH** | immediately dangerous to life and health |
| **IFB** | invitation for bid |
| **IP** | ionization potential |
| **ISCO** | Instrumentation Specialists Company |
| **ITD** | Ion Trap Detector |
| **LEL** | lower explosive limit |
| **LL** | liquid limit |
| **LOD** | limits of detection |
| **LOQ** | limit of quantitation |
| **LSC** | liquid sample concentration |
| **LT** | less than |
| **LUST** | leaking underground storage tank |
| **LVZ** | low-velocity layer |
| **MAD** | maximum applicable dose |
| **MDL** | Method Detection Limit |
| **m/sec** | meters per second |
| **MHz** | megahertz |
| **MS/MS** | Mass Spectrometer/Mass Spectrometer |
| **NBS** | National Bureau of Standards |
| **NCDC** | National Climatic Data Center |
| **NCIC** | National Cartographic Information Center |
| **NCP** | National Contingency Plan |
| **NEIC** | National Enforcement Investigation Center |
| **NGVD** | National Geodetic Vertical Datum |
| **NIOSH** | National Institute for Occupational Safety and Health |
| **NMO** | normal moveout |
| **NOAA** | National Oceanographic and Atmospheric Administration |
| **N.O.S** | not otherwise specified (used in shipping hazardous material) |
| **NPDES** | National Pollution Discharge Elimination System |
| **NPL** | National Priorities List |
| **NRC** | Nuclear Regulatory Commission |

| | |
|---|---|
| NSF | National Sanitation Foundation |
| NTIS | National Technical Information Service |
| NWS | National Weather Service |
| OD | outside diameter |
| OERR | EPA Office of Emergency and Remedial Response |
| OSHA | Occupational Safety and Health Administration |
| OSWER | EPA Office of Solid Waste and Emergency Response |
| OT | oral temperature |
| OVA | Organic Vapor Analyzer (onsite organic vapor monitoring device) |
| OWPE | EPA Office of Waste Programs Enforcement |
| PARCC | Precision, Accuracy, Representativeness, Completeness, Comparability |
| PCBs | polychlorinated biphyenyls |
| PDS | personnel decontamination station |
| PE | potential electrode |
| PEL | permissible exposure limit |
| PHC | principal hazardous constituents |
| PI | plasticity index |
| PID | photo ionization detector |
| PL | plastic limit |
| PO | EPA Headquarters Project Officer |
| POTWs | publically owned treatment works |
| ppb | parts per billion |
| PPE | personal protective equipment |
| ppm | parts per million |
| PRP | Potentially Responsible Party |
| psig | pounds per square inch gauge |
| PVC | polyvinyl chloride |
| QA | quality assurance |
| QA/QC | quality assurance/quality control |
| QAMS | Quality Assurance Management Staff |
| QAPjP | Quality Assurance Project Plan (see QAPP) |
| QAPP | former abbreviation for Quality Assurance Plan (see QAPjP) |
| QC | quality control |
| RA | remedial action |
| RAS | Routine Analytical Service |
| RCRA | Resource Conservation and Recovery Act of 1978 (PL 94-580) |
| RD | remedial design |
| RDCO | Regional Document Control Officer |
| REM | Remedial Planning |
| REM/FIT | Remedial Planning/Field Investigation Team |
| RI | Remedial Investigation |
| ROD | Record of Decision (previous title for Remedial Project Manager) |
| RPM | EPA Remedial Project Manager |
| RSPO | Remedial Site Project Officer |
| RSCC | Regional Sample Control Center |
| RTDs | resistance temperature detectors |
| SARA | Superfund Amendments and Reauthorization Act of 1986 (PL 99-499) |
| SAS | Special Analytical Service |
| SDL | Sample Detection Limit |
| SI | Site Inspection |
| SI units | International System of Units |
| SIM | Selected Ion Monitoring |
| SCBA | self-contained breathing apparatus |
| SCS | Soil Conservation Service |
| SDWA | Safe Drinking Water Act |

| | |
|---|---|
| **SMCRA** | Surface Mining Control and Reclamation Act |
| **SMO** | Sample Management Office |
| **SM** | Site Manager |
| **SOPs** | standard operating procedures |
| **SP** | spontaneous potential |
| **SPM** | Site Project Manager (previous title for Site Manager) |
| **SRM** | Standard Reference Material |
| **SSC** | Site Safety Coordinator (see also SSHO, SSO, and HSO) |
| **SSHO** | Site Safety and Health Officer (see also SSC, SSO, and HSO) |
| **SSO** | Site Safety Officer (see also SSC, SSHO, and HSO) |
| **STAPPA/ ALAPCO** | the State and Territorial Air Pollution Program Administrators and the Association of Air Pollution Control Officials |
| **STAR** | Stability Array |
| **TAL** | Target Analyte List |
| **TAT** | technical assistance team |
| **TCDD** | 2,3,7,8-tetrachlorodibenzo-p-dioxin |
| **TEGD** | Technical Enforcement Guidance Document |
| **TDD** | Technical Directive Documents |
| **TDS** | total dissolved solids |
| **TIC** | Tentatively Identified Compounds |
| **TLD** | thermoluminescent detector |
| **TLD badge** | Thermoluminescent detector badge |
| **TLV** | threshold limit value |
| **TOC** | Total Organic Carbon |
| **TOH** | Total Organic Halogen |
| **TOX** | Total Organic Halides |
| **TR** | traffic report |
| **TSCA** | Toxic Substances Control Act |
| **TSDF** | reatment, Storage, and Disposal Facility |
| **UEL** | upper explosive limit |
| **UNAMAP** | User's Network for Applied Modeling of Air Pollution |
| **U.S. EPA** | U.S. Environmental Protection Agency |
| **USCS** | Unified Soil Classification System |
| **USDI** | U.S. Department of Interior |
| **USGS** | U.S. Geological Survey |
| **USPS** | U.S. Postal Service |
| **UV** | ultraviolet |
| **VOA** | volatile organic analysis |
| **VOC** | Volatile Organic Compound |
| **WAs** | Work Assignments |
| **WP** | work plans |

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# SECTION 1

# USE OF THE COMPENDIUM

## 1.1 SCOPE AND PURPOSE

*Webster's Third New International Dictionary* (Unabridged) defines " compendium " as:

- A. A brief compilation or composition consisting of a reduction and condensation of the subject matter of a larger work
- B. A work treating in brief form the important features of a whole field of knowledge or subject matter category

While the reader may take exception to the use of the word "brief" to describe this compendium, the two volumes represent an astoundingly reduced version of the many field operations methods that have been used during remedial response activities at hazardous waste sites. This compendium focuses primarily on techniques and methods used during the fieldwork phase of a remedial investigation. Exhibits 1-2 and 1-3 emphasize this orientation, and provide the reader with a guide to the applicability of the various sections to the Remedial Investigation / Feasibility Study (RI/FS) process. The compendium also provides some limited information on those subjects for which extensive guidance exists elsewhere, such as project planning and management, quality control, decontamination, and health and safety issues. These latter subjects are addressed only briefly, primarily to guide the reader into an appreciation of how the various facets of project management and execution are interrelated.

The compendium was written primarily to assist the Site Manager (SM). The SM is the individual who is responsible for the successful execution of a work assignment, and who may be an employee of the EPA, state agency, Potentially Responsible Party (PRP), or contractor. Generally, the compendium addresses the SM as a contractor's employee who is working with an EPA Remedial Project Manager (RPM) at the regional project level on a Superfund program, such as Field Investigation Team (FIT) or Remedial Planning Activities (REM II, III, or IV). The EPA management structure includes a Regional Project Officer, who oversees implementation of a program at the EPA regional level, and a Project Officer at EPA Headquarters, who is responsible for program guidance Agency-wide. Management structures vary with the contractors' organization.

This compendium is one of a series of guidance and technical documents of which the Site Manager and, to a lesser degree, task leaders and field workers should be aware before beginning fieldwork. These documents are listed in Exhibit 1-1.

The list of applicable guidance is far from complete; a more detailed (but still incomplete) list of guidance and technical resource documents, and their relationship to RI/FS phases and tasks is contained in Appendix 1A. Subsequent sections of the compendium will list other helpful references under the heading "Information Sources."

## Exhibit 1-1
## GUIDANCE AND TECHNICAL DOCUMENTS

- *Guidance on Remedial Investigations Under CERCLA* (EPA 540/G-85/002)
- *Guidance on Feasibility Studies Under CERCLA* (EPA 540/G-85/003)
- *Superfund Remedial Design and Remedial Action Guidance* (OSWER Directive 9355.0-4A)
- *Superfund Public Health Evaluation Manual* (OSWER Directive 9285.4-1)
- *Superfund Exposure Assessment Manual* (OSWER Directive 9285.5-1)
- *Standard Operating Safety Guides* (OSWER Directive 9285.1-1B)
- *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities* (DHHS (NIOSH)Publication 85-115)
- *Data Quality Objectives for Remedial Response Activities* (OSWER Directive 9355.0-7B)
- *Samplers and Sampling Procedures for Hazardous Waste Sources* (EPA 600/2-80-018)
- *User's Guide to the Contract Laboratory Program* (OERR, December 1986)
- *EPA Regional Standard Operating Procedures, Guidelines and Directives*

---

The purpose of this compendium is to provide the reader with a summary of field techniques to use as references during preparation of project planning documents. The compendium does not contain a series of standard operating procedures to use as references in their entirety, but rather it may be used as a reference to a series of methods with project and site-specific modifications added. For example, a quality assurance project plan could present techniques for gathering data on chemical concentrations in fish tissues as shown in the following Example Citation.

**Example Citation**

---

**TASK 1. BIOTA EVALUATIONS**

**Subtask 1. A. Electrofishing in Mung Creek**

- **A. Limitations and Application** - Subsection 12.6.3.3, Aquatic (Freshwater) Field Methods Summary, pp.12-24 and 12-25, Section 12, Revision No. 0, *Compendium of Field Operations Methods* (COFOM #0).

- **B. Sampling Techniques** - Subsection D2, Electrofishing, Appendix 12A, pp. 12A-32 through 12A-35, COFOM #0.

  **Modifications** - Only carp will be collected. Specimens smaller than 8 inches in length and 2 pounds in weight will be released. Any specimens caught below 14th Street Bridge will be released. See site safety plan for boating and collection safety procedures.

- **C. Laboratory Techniques** - Subsection 12.6.3.3,pp. 12-23 and 12-24, Subsection E4, Appendix 12A, pp. 12A-41 through 12A-46, COFOM #0.

  **Modifications** - See CLP SAS in Task 4, Sample Analysis

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The compendium will be available to every EPA region and contractor and can serve as a common source for methods citation, as indicated above.

## 1.2 DEFINITIONS AND ABBREVIATIONS OR ACRONYMS

Each section of the compendium defines terms specific to that section and deciphers abbreviations or acronyms when they are first used. A glossary is furnished in the beginning of each volume. The most frequently used abbreviation is defined below.

**Site Manager (SM)**
The individual who is responsible for the successful execution of a work assignment. SM usually refers to a contractor's employee.

## Exhibit 1-2
## RELATIONSHIP AMONG STANDARD RI/FS TASKS AND THE COMPENDIUM

| Description of Standard RI/FS Tasks and Subtasks | Applicable Sections and Subsections of the "Compendium of Field Operations Methods"* |
|---|---|
| Project Planning | 2, 3.2, 3.3, 3.4, 4, 5, 6, 16<br>17, 18, 19, 20 |
| Community Relations | Not directly applicable |
| Field Investigations | |
| Project management | 2, 3, 17, 18, 19, 20 |
| Quality control | Throughout; procedure specific |
| Fieldwork, air | 7, 11, 15 |
| Fieldwork, biota | 12 |
| Fieldwork, close support laboratories | 5.2, 7, 15 |
| Fieldwork, RI-derived waste disposal | 3.2, 5.2.6.4, 8.1.6.3 |
| Fieldwork, soil gas | |
| Fieldwork, support | 3, 17, 18, 19, 20 |
| Fieldwork, well logging | 8.1, 8.3 |
| Fieldwork, mapping and survey | 14 |
| Fieldwork, geophysical | 8.4 |
| Fieldwork, well installation | 8.1, 8.5 |
| Fieldwork, groundwater | 8.5 |
| Fieldwork, soil | 8.1, 8.2, 8.3 |
| Fieldwork, source testing | 7, 13, 15 |
| Fieldwork, surface water | 10 |
| Sample Analysis | |
| Fieldwork, close support laboratory | 5.2, 15 |
| Data validations | 16 |
| Sample management | 4, 5, 6 |
| Data Evaluation | 16 |
| Assessment of Risk | Not directly applicable |
| Treatability Study/Pilot | 9 (soils engineering data) |
| Remedial Investigation Reports | Not directly applicable |
| Remedial Alternatives Screening | Not directly applicable |
| Remedial Alternative Evaluation | Not directly applicable |
| Feasibility Study RI/FS Reports | Not directly applicable |
| Post RI/FS Support | Not directly applicable |
| Enforcement Support | Not directly applicable |
| Miscellaneous Support | Not directly applicable |
| ERA Planning | Not directly applicable |

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*See Exhibit 1-3 for titles.

## Exhibit 1-3

## TITLES OF SUBJECTS IN "COMPENDIUM OF FIELD OPERATIONS METHODS"

**Section and Subsection**

1. Use of the Compendium

2. Preparation of Project Description and Statement of Objectives

3. Implementing Field Activities
   - 3.1 General Considerations
   - 3.2 Control of Fieldwork-Generated Contaminated Material
   - 3.3 Organization of the Field Team
   - 3.4 Decontamination
   - 3.5 General Health and Safety Considerations

4. Sample Control, Including Chain of Custody

5. Laboratory Interface
   - 5.1 National Contract Laboratory Program
   - 5.2 Noncontract Laboratory Program
     - 5.2.6.4 Residual Samples and Analytical Wastes

6. Sample Containers, Preservation, and Shipping
   - 6.1 Sample Containers and Preservation
   - 6.2 Packaging, Labeling, and Shipping

7. Field Methods for Rapid Screening for Hazardous Materials

8. Earth Sciences
   - 8.1 Geologic Drilling
   - 8.2 Test Pits and Excavations
   - 8.3 Geological Reconnaissance and Geological Logging
   - 8.4 Geophysics
   - 8.5 Groundwater Monitoring

9. Earth Sciences Laboratory Procedures
   - 9.6.2 Laboratory Selection
   - 9.6.3 Physical Properties
   - 9.6.4 Chemical Properties of Soil and Rock
   - 9.6.5 Compatibility Testing
   - 9.6.6 Laboratory and Analysis Records

10. Surface Hydrology
    - 10.1 Flow Measurement
    - 10.2 Sampling Techniques

11. Meteorology and Air Quality

**Exhibit 1-3**
**(continued)**

12. Biology/Ecology
    - 12.6.1 Presence of Toxic Substances
    - 12.6.2 Field Collection Techniques--General
    - 12.6.3 Field Methods--Specific
        - 12.6.3.2 Terrestrial Field Methods Summary
        - 12.6.3.3 Aquatic (Fresh Water) Field Methods Summary
        - 12.6.3.4 Marine Field Methods Summary
    - 12.6.4 Laboratory Tests and Analyses

13. Specialized Sampling Techniques
    - 13.1 Wipe Sampling
    - 13.2 Human Habitation Sampling
    - 13.3 TCDD Sampling
    - 13.4 Container Sampling

14. Land Surveying, Aerial Photography,and Mapping

15. Field Instrumentation

16. Data Reduction, Validation, Reporting, Review, and Use

17. Document Control

18. Corrective Action

19. Quality Assurance Audit Procedures

20. Quality Assurance Reporting

## 1.3 APPLICABILITY

The techniques presented in this compendium may be used in remedial response activities conducted for or by the EPA. Other entities (state agencies, other federal agencies, or private concerns) may also find the techniques useful. All of the methods presented have been used by EPA contractors in executing fieldwork. Some of EPA's region-specific standard operating procedures, which are referenced in each section of this compendium, may take precedence over these more general methods (see Subsection 1.6).

The procedures are written for the trained, experienced professional who should realize that every hazardous waste site is discrete and every work assignment is different. Every hazardous waste site requires a degree of personal protection, a monitoring system to detect hazards, and an adaptation of work procedures to site conditions. The user should realize that not all procedures are suitable for use, or can even be accomplished, with every level of personal protection. The amount of time spent executing a procedure and the number of trained, experienced people needed to accomplish the work will increase dramatically as the need for personal protection increases.

## 1.4 RESPONSIBILITY

The Site Managers bear prime responsibility for selection of the proper methods to accomplish the goals and objectives of their work assignments. The SM uses the capabilities of various technical specialists and the data quality objectives to precisely determine the methods used. Senior management and the clients provide quality assurance and quality control (QA/QC), and overall direction.

## 1.5 UPDATES

The compendium represents a snapshot of methods and techniques that, in the rapidly evolving field of remedial response, will undergo changes as new procedures are defined. Additionally, methods that were not included in this compendium because of a lack of demonstrated success at the time of writing may rapidly emerge as methods of choice. EPA's intent is to provide periodic updates presenting newly evolved methods and improvements on "old" methods. Comments, suggestions, and recommended procedures are solicited from the users. Please address such material to:

Ms. Lisa Woodson Feldt
U.S. EPA (WH548E)
401 M Street, SW
Washington, DC 20460

## 1.6 REGION-SPECIFIC VARIANCES

As stated, these procedures have been used by EPA contractors during remedial response activities. Variances specific to the various EPA regions are listed in each section. These variances were updated using information supplied by the regions for this version and were current at publication. However, because performance requirements vary among EPA contracts, among EPA regions, within EPA regions, and even among tasks on the same work assignments, users of this compendium are strongly urged to consult the appropriate EPA official to obtain the most current variations to the methods listed in this compendium. Some regions, such as the Engineering Support Branch in Region IV, have published a detailed standard operating procedure for use by persons executing fieldwork.

# Appendix 1A
# INTERRELATIONSHIP AMONG POLICY GUIDANCE, TECHNICAL RESOURCE DOCUMENTS, AND THE RI/FS PHASES AND TASKS

| RI/FS Phases/Tasks | Primary or Policy Guidance (SARA & NCP for All ) | Secondary or Technical Resource Documents |
|---|---|---|
| SCOPING<br>Collection and Analyses of Existing Data | Data Quality Objectives for Remedial Response Activities (EPA, 3/87) | |
| | Data Quality Objectives for Remedial Response Activities (EPA, 3/87) | Management of Hazardous Waste Leachate, SW 871 (EPA, 1982) |
| | Guidance Document for Cleanup of Surface Tank and Drum Sites (EPA, 5/85) | Leachate Plume Management (EPA, 11/85) |
| Identification of Preliminary Remedial Action Alternatives | Guidance Documents for Cleanup of Surface Impoundment Sites (EPA, 6/86) | |
| | Handbook on Remedial Action on Waste Disposal Sites (EPA, 10/85) | |
| | Other draft documents not yet in circulation (e.g., groundwater remediation guidance, landfill guidance, etc.) | |
| Identification on ARARs | CERCLA Compliance with other Environmental Statutes (EPA, 10/85) | |
| Identification of Data Needs and Sampling Strategies Activities | Data Quality Objectives for Remedial Response (EPA, 3/87) | |
| Health and Safety Planning | Occupational Safety and Health: Guidance Manual for Hazardous Waste Site Activities (NIOSH, 10/85) | Standard Operation Safety Guides (EPA, 11/84) |
| SAP (QAPjP/FSP) | A Compendium of Field Operations Methods (3/84) | Sediment Sampling Quality Assurance Users Guide (EPA, 7/85) |
| | | Soil Sampling Quality Assurance Users Guide (EPA, 5/84) |
| Work Plans | | Federal-Lead Remedial Project Management Handbook (EPA, 12/86) |
| | | State-Lead Remedial Project Management Handbook (EPA, 1/86) |
| Go to RI Phase I and FS Phase I | | |

## Appendix 1A
## (continued)

| RI/FS Phases/Tasks | Primary or Policy Guidance (SARA & NCP for All ) | Secondary or Technical Resource Documents |
|---|---|---|
| RI Phase I | | |
| Field Investigation | A Compendium of Field Operations Methods (3/84) | Test Methods for Evaluation of Solid Waste, 2nd Edition (EPA, 6/86) |
| | | Geophysical Methods for Locating Abandoned Wells (5/84) |
| | | Geophysical Techniques for Sensing Buried Wastes and Waste Migration (EPA, 1984) |
| | | Practical Guide for Goundwater Sampling (EPA, 9/85) |
| Sample Analysis | A Compendium of Field Operations Methods (3/84) | |
| | User's Guide to the CLP | |
| Risk Assessment | Superfund Public Health Evaluation Manual (EPA, 12/85) | |
| | Superfund Exposure Assessment Manual (EPA, 5/86) | |
| Other Data Evaluation Methods | | Modeling Remedial Actions at Uncontrolled Hazardous Waste Sites (EPA, 4/85) |
| Refinement of Remedial Action Objectives | Data Quality Objectives for Remedial Response Activities (EPA, 3/87) | |
| Go to FS Phase I | | |

## Appendix 1A
(continued)

| RI/FS Phases/Tasks | Primary or Policy Guidance (SARA & NCP for All ) | Secondary or Technical Resource Documents |
|---|---|---|
| FS Phase I | | |
| Identification of Potential Technologies | Guidance Document for Cleanup of Surface Tank and Drum Sites (EPA, 5/85)<br>Handbook on Remedial Actions at Uncontrolled Hazardous Waste Sites (4/85) | Management of Hazardous Waste Leachate, SW 871 (EPA, 1982)<br>Leachate Plume Management (EPA, 11/85)<br>Mobile Treatment Technologies for Superfund Wastes (EPA, 9/86)<br>Review of In-Place Treatment Techniques for Contaminated Surface Soils (EPA, 7/84)<br>Treatment Technology Briefs: Alternatives to Hazardous Waste Landfills (EPA, 7/86)<br>Handbook for Stabilization/Solidification of Hazardous Wastes (EPA, 9/86)<br>System to Accelerate In Situ Stabilization of Waste Disposal (EPA, 9/86)<br>Slurry Trench Construction for Pollution Migration Control (EPA, 2/84) |
| Technology Screening | Handbook of Evaluating Remedial Action Technology Plans (EPA, 8/83)<br>Directory of Commercial Hazardous Waste Treatment and Recycling Facilities (EPA, 12/85) | |
| Assembly of Alternatives | | |

Go to FS Phase II

## Appendix 1A
## (continued)

| RI/FS Phases/Tasks | Primary or Policy Guidance (SARA & NCP for All ) | Secondary or Technical Resource Documents |
|---|---|---|
| FS PHASE II | | |
| Alternative Evaluation: | | |
| - Effectiveness | Modeling Remedial Actions at Uncontrolled Hazardous Waste Sites (EPA, 4/85)<br>Superfund Public Health Evaluation Manual (EPA, 12/85) | |
| - Implementability | | Directory of Commerical Hazardous Waste Treatment and Recycling Facilities (EPA, 12/85)<br>Petitions to Delist Hazardous Waste: A Guidance Manual (EPA, 4/85) |
| - Cost | Costs of Remedial Response Actions at Uncontrolled Hazardous Waste Sites (EPA, 1981)<br>Remedial Action Costing Procedures Manual (EPA, 9/85) | |
| Alternative Screening | | |
| Go to RI Phase II or FS Phase III | | |
| RI PHASE II | | |
| Bench-Scale Testing | | |
| Pilot Testing | Practical Guide-Trial Burns for Hazardous Waste Incinerators-- Project Summary (EPA, 7/86) | |
| Go to FS Phase III | | |

## Appendix 1A
## (continued)

| RI/FS Phases/Tasks | Primary or Policy Guidance (SARA & NCP for All ) | Secondary or Technical Resource Documents |
|---|---|---|
| FS PHASE III | | |
| Detailed Evaluation: | | |
| - Effectiveness | Modeling Remedial Actions at Uncontrolled Hazardous Waste Sites (EPA, 4/85)<br>Superfund Public Health Evaluation Manual (EPA, 12/85)<br>Superfund Remedial Design and Remedial Action Guidance (EPA, 2/85) | |
| - Implementability | | Directory of Commercial Hazardous Waste Treatment and Recycling Facilities (EPA, 12/85)<br>Petitions to Delist Hazardous Waste: A Guidance Manual (EPA, 4/85) |
| - Cost | Costs of Remedial Response Actions at Uncontrolled Hazardous Waste Sites (EPA, 1981)<br>Remedial Action Costing Procedures Manual (EPA, 9/85) | |
| Summary | | |
| COMMUNITY RELATIONS | Community Relations in Superfund: A Handbook (EPA, 3/86) | |

# SECTION 2

# PREPARATION OF PROJECT DESCRIPTION AND STATEMENT OF OBJECTIVES

## 2.1 SCOPE AND PURPOSE

This section describes the information that should be addressed in the "project description and statement of objectives" section of a field activities plan. The information discussed below is applicable to all such plans, but it should be modified to meet the needs of a specific project.

A section entitled "project description and statement of objectives" should be included in all response activity plans; such a section is required in the quality assurance and sampling plans for remedial investigations and in work plans for Field Investigation Team (FIT) operations. Project descriptions are also used as input to the site safety plan. The project description defines the goals of the project and describes how the information necessary to meet the project goals will be obtained. The project description should provide the reader with enough information to judge the appropriateness and adequacy of the quality assurance, work, or sampling plans. The project description and statement of objectives are integral elements in the development of data quality objectives, which are qualitative and quantitative statements that outline the decision-making process for remedial responsibilities and specify the data required to support those decisions. Extensive guidance on development of data quality objectives exists (OSWER Directive 9355.0-7B) and will not be repeated within this document.

## 2.2 DEFINITIONS

**Analytical Parameters**
Chemical constituents and levels of detection required for sample analysis. Parameters also include field measurements (e.g., pH, groundwater levels), engineering soils data (e.g., soil permeability, particle size analysis), and Contract Laboratory Program (CLP) Special Analytical Services (SAS) components.

**Quality Assurance Project Plan (QAPjP)**
The policies, organization, objectives, functional activities, and specific QA and Quality Control (QC) activities designed to achieve the data quality goals of the specific project(s) or continuing operation(s).

**Sample Matrix**
Media from which the sample is collected (e.g., soil, groundwater, surface water).

**Sampling Plan**
A program of action that is developed prior to field activities and that describes the methods and procedures for obtaining representative portions of the environment being investigated.

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

## 2.3 APPLICABILITY

Remedial response activities, such as field investigation and sample collection, require a written plan that should include a project description. The description should be included in its entirety and may not be referenced from another document.

## 2.4 RESPONSIBILITIES

The Site Manager or designated person who is responsible for writing the work plan, sampling plan, or quality assurance project plan is also responsible for the section on project description and statement of objectives.

## 2.5 RECORDS

The project description and statement of objectives constitute the record. Pertinent information that is used to develop the project description should be recorded and maintained by the SM.

Such information would include results of previous site investigations; any environmental permits associated with the site; tax records; results of inspections by other state, local, or federal agencies; newspaper accounts; records from community relations interviews; aerial photography (such as those typically available from the Environmental Photographic Interpretation Center); and any other data that will assist the SM in developing the project description and statement of objectives. It is important, particularly on projects involving enforcement activities, that adequate records be kept to document the process by which project objectives were derived. Project objectives determine sampling strategy and are directly related to the final costs of the response activities, the adequacy of the feasibility study, and the success of the remedial alternative. Meeting notes, telephone conversation records, assumptions regarding interpretations of work assignments, and other records pertaining to the development of the project description and statement of objectives should be maintained in a manner that will allow the SM and project team to reconstruct the decision-making process that led to the stated project objectives.

## 2.6 PROCEDURES

The project description should be site-specific and include at least the following items:

- Site description and history
- Schedule of activities
- Intended data usage
- Identification of sample matrices and parameters
- Sample design description and rationale

Each of these items are described below.

### 2.6.1 Site Description and History

The site description should include all pertinent physical and land use information. Maps, drawings, and photographs should be included, if available. The following information should be provided:

- Size, including area within facility boundaries and the extent of contamination above defined thresholds, if known (See also Section 17 for discussion of background levels used as a defined threshold.)
- Specific location description including directions and distances from nearby towns
- Surrounding geography (e.g., town, city, county, or state boundaries and jurisdictions; power lines; railroads; roads; and topography)
- Physical description including the following:
    - Geologic conditions
    - Soil types and depths
    - Surface water hydrology
    - Groundwater hydrology
    - Flora
    - Fauna
    - Terrain
- Onsite conditions (e.g., the presence of pits, ponds, tanks, drums, standing water, buildings, and wells)
- Climatological description for the region and for site-specific parameters, such as wind speed and direction, precipitation patterns, and freezing conditions
- Demographics and surrounding land use (e.g., agricultural, industrial, or residential; populace at risk; and transportation patterns)

Relevant historic facts about the site should be included in the project description. Following are examples of useful historic information:

- Past and present uses of the site
- Identification of onsite facilities and description of activities at these facilities, including any facilities that have been demolished and any subsurface facilities (e.g., tanks, utilities, and vaults)

- Onsite disposal and materials handling practices
  - Areas used for disposal and methods of disposal (tanks, drum, pit, pond, lagoon, landfill, land treatment, etc.)
  - Material storage or transfer facilities and areas onsite, including spills or dumps

- Description of wastes onsite
  - Quantity
  - Physical state
  - Chemical identification, if known
  - Location

- Prior complaints or agency actions concerning the site including any permits held by the site (Permit applications are also of interest, even if no permit was awarded.)

- Prior sampling activities onsite or near the site, and the resultant data (This information should be evaluated in terms of the confidence held in the data and of the intended usage of that data.)

- Prior remedial or response activities

- Prior accidents or incidents onsite, such as fires, explosions, or chemical releases

A detailed site history should be completed before initiating any activities onsite. A brief summary of the site history, which includes information that may affect sampling plans, work plans, the site safety plan, or the quality assurance plan, should be included in the project description. The reliability of the information should be assessed, and the acceptability of the existing data for intended use should be determined.

### 2.6.2 Schedule of Activities

The project schedule should include project milestones, such as the startup date for the project, field investigation dates, the data review period, and dates when reports are due. The activity(s) addressed by quality assurance and work sampling plans should be identified. The expected start and finish dates for the project and the field work must be stated. A diagram, flow chart, or critical path chart should be included to help the reader understand the project.

### 2.6.3 Intended Data Usage

To determine whether the work, sampling, and quality assurance plans will generate data that meet the project objectives, it is necessary to define the types of decisions that will be made, identify the intended use of the data, and design a data collection program. Data quality objectives (DQO) are defined as "an integrated set of thought processes which define data quality requirements based on the identified end use of the database" (OSWER Directive 9355.0-7B). The DQOs are useful in developing a sampling plan and analytical plan so that sufficient data of known, defensible quality are obtained to assist the decision-makers in arriving at sound decisions concerning remedial response activities. The DQO, based on the intended use of the data, will assist in determining the appropriate detection limits, analytical methods, and sample handling procedures (chain-of-custody requirements, as well as preservation and holding times).

Possible uses for the data are listed below :

- Confirm suspected contaminants or concentrations of contaminants.
- Qualitatively assess the nature and extent of contamination.
- Design additional sampling campaigns.
- Implement operable units involving cleanup and removal.
- Compare with established criteria (e.g., drinking water standards and National Pollution Discharge Elimination System (NPDES) requirements).
- Assess exposure, endangerment, and risks.
- Screen or select remedial alternatives.
- Use as input to the conceptual design of remedial technologies.
- Use in future enforcement actions and litigation. The applicable legislation (CERCLA, RCRA, TSCA, etc.) should be identified.

The specific purpose of the site investigation should be stated. The use of the data as a qualitative or quantitative measure should be specified. Discrete quantitative requirements for the data, such as a level of detection required for comparison with health criteria, should also be specified.

### 2.6.4 Identification of Sample Matrices and Parameters

Identification of the appropriate sample matrices and parameters should be included in the project description. A table similar to Exhibit 2-1 may suffice. A listing of compounds should be included. Any special sample handling requirements (e.g., filtering and dry weight analyses) should be identified in this section. Parameters for special analytical services and geotechnical and hydrogeological investigations should also be identified.

### 2.6.5 Sampling Design Description and Rationale

A brief description of the sampling design and rationale should be included in the project description. DQO guidance addresses sampling design description and rationale. If DQO guidance is followed, a single scoping section covering anticipated remedies, data requirements, and sampling should result. The sampling design description should include potential sampling locations and parameters. A rationale for choosing the sampling points, number of samples, medium of sample (air, soil, or water), sampling methods, amounts, preservation techniques and chemical parameters should be discussed. Sample containers, preservation techniques, and shipping methods should be selected in accordance with the latest

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## Exhibit 2-1
## SAMPLING FOR XYZ SITE

| | Target Compound List Organics (No. x Freq. = Total) | Target Compound List Inorganics[a] Tasks I & II Metals Task III Cyanide (No. x Freq. = Total) | Special Analytical Services (No. x Freq. = Total) |
|---|---|---|---|
| Groundwater | | | |
| Monitoring Well | 19 x 2 = 38 | 19 x 2 = 38 | - |
| Residential Wells[b] | 10 x 2 = 20 | 5 x 2 = 10 | 5 x 2 = 10 |
| Surface Water | | | |
| Water | 6 x 1 = 6 | 6 x 1 = 6 | - |
| Sediment | 6 x 1 = 6 | 6 x 1 = 6 | - |
| Soils | | | |
| Chemical | 46 x 1 = 46 | 46 x 1 = 46 | - |
| Physical | - | - | 25 x 1 = 25[c] |

---

[a] Groundwater sample to be analyzed for total cyanide and total metals will not be filtered before analysis. An aliquot will be filtered in the field before sample preservation, and will be analyzed for soluble metals and soluble cyanide. Detection limit requirements are specified in "QAPjP for XYZ Site, Appendix A, Analytical Requirements."

[b] SAS will be used to analyze residential well samples for ammonia, nitrates and nitrites.

[c] 10 Atterberg limits, 15-grain-size distribution.

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EPA and Department of Transportation (DOT) requirements. Sections 4, 5, and 6 of this compendium contain information on these procedures; however, consultation with EPA and DOT is strongly recommended.

## 2.7 REGION-SPECIFIC VARIANCES

No specific regional variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPMs for full details on current regional practices and requirements.

## 2.8 INFORMATION SOURCES

U.S. Environmental Protection Agency. *"Data Quality Objectives: Development Guidance for Uncontrolled Hazardous Waste Site Remedial Response Activities."* OSWER Directive 9355.0-7B, Sections B, C, D, and F. Washington, D.C.: Hazardous Site Control Division. 1 April 1987.

U.S. Environmental Protection Agency. *Guidance for Preparation of Quality Assurance Project Plans.* QAMS, 005/80. Washington, D.C.

U.S. Environmental Protection Agency. *Guidance for the Development of a Quality Assurance Plan.* Prepared by Regional Team: Juanita Hillmar (Region VIII), Ho L. Young (Region IX), and Barry Towns (Region X).

U.S. Environmental Protection Agency. *Preparation of State-Lead Remedial Investigation Quality Assurance Project Plans for Region V; Guidance.* Quality Assurance Office. Chicago, Illinois.

# SECTION 3

# IMPLEMENTING FIELD ACTIVITIES

## 3.1 GENERAL CONSIDERATIONS

### 3.1.1 Scope and Purpose

Section 3 addresses several areas including the control of contaminated materials generated during fieldwork, organization of the field team, decontamination, and general health and safety considerations. This section provides general information on those topics in individual subsections that identify their relevant scope and purpose, definitions, and applicability. The section lists information sources for specific guidance. Fieldwork encompasses the activities associated with preliminary assessments / site inspections (PA/SI), site investigations, remedial investigations (RI), feasibility study, pilot or bench tests, and Resource Conservation and Recovery Act (RCRA) inspections. Guidance on these activities is voluminous and will not be presented here. The Site Manager (SM) must also be guided by the state and local laws, codes, rules, regulations, and ordinances, as well as by any site-peculiar guidance such as consent decrees.

### 3.1.2 Definitions

**Office of Safety and Health Administration (OSHA) 1910.120**

OSHA Interim Final Rule on Hazardous Waste Operations and Emergency Response. OSHA Standard 29 CFR 1910.120 as released on 19 December 1986 in the *Federal Register.*

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

### 3.1.3 Applicability

The procedures contained in Section 3 are applicable to field activities that involve hazardous materials (as defined by the OSHA standard) and are a potential for personnel exposure.

### 3.1.4 Responsibilities

Activities that fall under the scope of OSHA 29 CFR 1910.120, as defined in that standard, must comply with the requirements of that standard. The SM is responsible for coordinating all efforts with the assigned Health and Safety Officer (HSO) [also known as Site Safety Coordinator (SSC) or Site Safety and Health Officer (SSHO)] to achieve and maintain compliance.

### 3.1.5 Records

The documents required by OSHA 29 CFR 1910.120 must be completed, maintained, and made available as described in that standard. These records include medical surveillance documents, health and safety plans, and all other required documentation. The retention time for these documents is significant – 30 years or more. Site Managers must rely on the administrative personnel associated with their corporate or agency health and safety programs to provide for retention of records. These procedures should be clearly delineated within the program.

### 3.1.6 Procedures

Appropriate procedures are specified in the subsequent subsections.

## 3.2 CONTROL OF FIELDWORK-GENERATED CONTAMINATED MATERIAL

### 3.2.1 Scope and Purpose

Field investigation activities often result in the production or migration of contaminated materials (investigation-derived waste) that must be properly managed to protect the public and the environment, as well as to meet legal requirements. This subsection deals with the proper management of contaminated materials.

The objective of this guideline is to provide general reference information on the control of contaminated materials.

### 3.2.2 Definitions

**Contaminated Material**

Any of the field investigation's by-products that are suspected of being contaminated or are known to be contaminated with hazardous substances. These by-products include such materials as decontamination solutions, disposable equipment, drilling muds and cuttings, well-development fluids, well-purging water, and spill-contaminated materials.

### 3.2.3 Applicability

The SM should assume that hazardous wastes generated during an investigation will require compliance with federal requirements for generation, storage, transportation, or disposal. In addition, there may be state regulations that govern the disposal action.

The work plan for a site investigation must include a description of control procedures for contaminated materials. This plan should assess the type of contamination, estimate the amounts that would be produced, describe containment equipment and procedures, and delineate storage or disposal methods. Adequate budget must be allocated for these purposes. As a general policy, it is wise to select investigation methods that minimize the generation of contaminated materials. The handling and the disposing of potentially hazardous materials are expensive; however, the consequences and penalties for improper handling are significant.

### 3.2.4 Responsibilities

The Site Manager or designee is responsible for identifying as contaminated, any material that was generated onsite and for implementing the procedures used to control and dispose of such material.

### 3.2.5 Records

If onsite or offsite testing is conducted on the contaminated material, appropriate chain-of-custody and sample analysis forms must be prepared as described in other sections of this compendium. If it is determined that wastes generated onsite are hazardous, the appropriate RCRA manifest and disposal forms must be completed as discussed in Subsection 3.2.6.2. The SM must determine who will be designated as the generator of the contaminated material. Typically, an EPA official should be designated as the person to sign items such as manifests.

### 3.2.6 Procedures

Provided below is a broad description of the sources of contaminated material that can be generated onsite, plus a general discussion of the current procedures used to control and dispose of contaminated materials that are fieldwork generated.

#### 3.2.6.1 Sources of Contaminated Materials and Containment Methods

**Decontamination Solutions:** Decontamination solutions and rinses must be assumed to contain the hazardous chemicals associated with the site, unless there are analytical or other data to the contrary. The solution volumes could vary from a few gallons to several hundred gallons in cases where large equipment requires cleaning.

Small amounts of rinse solutions, such as those generated by the personnel decontamination station (PDS), are best stored in 55-gallon drums (or equivalent containers) that can be sealed until ultimate disposal at an approved facility. As a rule of thumb, use of a temporary PDS will generate 55 to 110 gallons of decontamination solution per day for every five persons using it. The addition of showers and clothes washing machines, associated with a more permanent facility, will generate as much as 1,000 gallons per day per every five persons. If the amounts generated by a PDS exceed one or two 55-gallon drums each day, a larger capacity above ground storage vessel, such as a fiberglass tank or collapsible rubber bladder, should be considered. If individual drums are used, they should be marked with sufficient information so that personnel can determine what contaminants may be present. This information should be based on the analytical results from the sampling campaign. Alternately, samples can be analyzed from each drum. However, the cost of analysis may exceed the cost of disposal. Larger containers may be sampled and analyzed in a cost-effective manner. If the suspected contamination is acceptably low, the fluids can be allowed to drain back onsite or can be released to local sewers - with the permission of the appropriate authorities. In some rare instances, contaminated fluids may be released back to the site.

Larger equipment, such as backhoes and tractors, must be decontaminated in an area that has a method of controlling and collecting the spent fluids. A decontamination area for large equipment can consist of a shallow depression lined with plastic, which is covered with clean sand or gravel, or the area may be a bermed concrete pad with a floor drain leading to a holding tank. The amounts generated by typical equipment cleaning devices (steam jenny and hydro-blaster) usually exceed 500 gallons per cleaning. Spill prevention and containment measures should be implemented for the larger fluid containers, or if many drums of fluid are left onsite. Protection from vandals is also needed.

**Disposable Equipment:** Disposable equipment that could be contaminated during a site investigation typically includes tools, rubber gloves, boots, broken sample containers, and chemically resistant clothing. These items are small and can easily be contained in 55-gallon drums with removable lids. Secure containment within the containers is provided by sealing them at the end of each work day and upon project completion. Additionally, containers are labeled in accordance with the applicable Department of Transportation (DOT) regulations on hazardous materials under 49 CFR 172.304. Adequate protection from vandals, theft, and adverse weather must be provided for all containers.

**Drilling Muds and Well-Development Fluids:** Drilling muds and well development fluids are materials used when installing groundwater monitoring wells. Their use could result in the surface accumulation of contaminated liquids and solids that require containment. Monitoring wells are often placed in uncontaminated areas to determine if hazardous chemicals have migrated below ground. Materials from these wells require especially careful management since they threaten contamination of otherwise clean property.

The volume of drilling and well-development fluids requiring containment will depend on the number of wells, diameters and depths, groundwater characteristics, and geologic formations. There are no simple mathematical formulas available for accurately predicting these volumes. It is best to rely on the experience of hydrogeologists and/or reputable well drillers who are familiar with the local conditions and the well installation techniques selected. These individuals should be able to estimate the volume of contaminated fluid to be contained. Since rough estimates may be involved, managers shall always be prepared to halt drilling or other well-development operations if more containment capacity is needed. For example, over one million gallons of contaminated fluids have been generated during pump tests of monitoring wells.

Drilling fluid (mud) is mixed and stored in a container commonly referred to as a mud pit. This mud pit consists of a suction section from which drilling fluid is withdrawn and pumped through hoses down the drill pipe to the bit and then back up the hole to the settling section of the mud pit. In the settling section, the fluid velocity is reduced by a screen and by several flow-restriction devices, thereby allowing the well cuttings to settle out of the fluid.

The mud pit may be either a portable aboveground tank, commonly made of steel, or a stationary pit that is in the ground. The aboveground tanks have a major advantage over pits in the ground because the tanks isolate the contaminated fluids from the surface environment. The tanks are also portable and can usually be cleaned easily.

As the well is drilled, the sediments that accumulate in the settling section must be removed. Removal is best done by shoveling sediments into drums or other similar containers. When the drilling is complete, the contents of the above ground tank are likewise shoveled or pumped into drums, and the tank is cleaned and made available for reuse.

If in-ground pits are used, they shall not extend into the natural water table. They shall also be lined with a bentonite-cement mixture followed by a layer of flexible impermeable material such as plastic sheeting. To maintain its impermeable seal, the material used must be nonreactive with the contaminants. An advantage of the in-ground pit is that well cuttings do not necessarily have to be removed periodically during drilling because the pit can be made deep enough to contain them. Depending on site conditions, the in-ground pit may have to be totally re-excavated and refilled with uncontaminated natural soils when the drilling operation is complete.

When the aboveground tank or the in-ground pit is used, a reserve tank or pit should be located at the site as a backup system for leaks, spills and overflows. In either case, surface drainage shall be such that any excess fluid can be controlled within the immediate area of the drill site. In-ground pits must also be barricaded and lighted to prevent accidents.

The containment procedure for well-development fluids is similar to that for drilling fluids. The volume and weight of contaminated fluid will be determined by the method of development. When a new well is bailed to produce clear water, substantially less volume and weight of fluid will result, than when backwashing or high-velocity jetting is used.

**Spill-Contaminated Materials:** A spill is always possible when a site investigation involves opening and moving containers of liquids. Contaminated sorbents and soils resulting from spills will have to be contained and cleaned up. Small quantities of spill-contaminated materials are usually best contained in drums, while larger quantities can be placed in lined pits or in other impermeable structures. In some cases, onsite containment may not be feasible and immediate transport to an approved disposal site will be required.

#### 3.2.6.2 Disposal of Contaminated Materials

Actual disposal techniques for contaminated materials are the same as those for any hazardous substance - incineration, landfilling and/or treatment. The problem centers around the assignment of responsibility for disposal. The responsibility must be determined and agreed on by all involved parties before the fieldwork starts.

If testing conducted on a waste that was generated onsite (RCRA extraction, organic screening, inorganic and organic analysis, etc.) shows that the waste is nonhazardous, the material can be handled as a non-RCRA waste and disposed of onsite at the direction of EPA. For hazardous waste materials, onsite disposal should not be practiced. The material should be properly packaged and disposed of in a RCRA-approved offsite facility. The same procedure applies to residuals of samples (see Section 5 for a discussion).

A majority of the waste material generated during onsite activities is hazardous. Either it is a health hazard, or the waste material when tested, fails the RCRA extraction tests. In these instances, EPA has provided guidance for the disposal of these materials. The guidance, in the form of a memorandum dated 13 December 1984 from Russel H. Wyer of EPA Headquarters, provides the general procedure for disposing of RCRA waste material from hazardous waste facilities. Site specific disposal options are developed by consulting with the EPA regions through the EPA RPM and by specifying disposal actions in the work plan.

#### 3.2.6.3 Waste Storage and Management

Wastes generated through investigative activities (e.g., drilling) are governed by RCRA requirements with regard to packaging, labeling, transporting, storing, and record keeping. These requirements are stated in 40 CFR 262 entitled "Standard Applicable to Generators of Hazardous Wastes." However, some state laws have primacy over RCRA requirements. To determine this, the appropriate state agency must be contacted. A list of the state environmental agencies has been attached for this use and appears as Exhibit 3-1.

Wastes that are accumulated through onsite activities are to be stored in a secure location that is under the control of the operator. Therefore, to meet this requirement, it is common practice for the waste-staging area to be located onsite. Wastes generated from offsite activities, such as wells, are addressed in standard 40 CFR 262.34(c). This standard states the generator "may accumulate as much as 55 gallons of hazardous waste or 1 quart of acutely hazardous waste...in containers at or near any point of generation where wastes initially accumulate, which is under the control of the operator of the process generating the waste...." Offsite wells are typically areas that cannot be considered to be under the operator's control. Therefore, the operator must place the wastes in containers and then label, manifest, and transport these wastes to the onsite staging area.

## Exhibit 3-1
## LISTING OF STATE ENVIRONMENTAL AGENCIES

ALABAMA
Department of Environmental
Management
State Capital
Montgomery, AL 36130
205/271-7700

ALASKA
Department of Environmental
Conservation
3220 Hospital Dr.
Pouch O
Juneau, AK 99811
907/465-2600

ARIZONA
Division of Environmental
Health Services
Department of Health Servs.
1740 W. Adams St.
Phoenix, AZ 85007
602/255-1130

ARKANSAS
Department of Pollution
Control and Ecology
8001 National Dr.
Little Rock, AR 72209
501/562-7444

CALIFORNIA
Resources Agency
1311 Resources Building
1416 9th St.
Sacramento, CA 95814
916/445-5656

COLORADO
Department of Natural
Resources
718 State Centennial Bldg.
1313 Sherman St.
Denver, CO 80203
303/866-3311

CONNECTICUT
Department of Environmental
Protection
117 State Office Bldg.
165 Capitol Ave.
Hartford, CT 06106
203/566-2110

DELAWARE
Division of Environmental
Control
Department of Natural
Resources and
Environmental Control
R and R Complex
89 Kings Highway
P.O. Box 1401
Dover, DE 19903
302/736-4764

DISTRICT OF COLUMBIA
Environmental Control
Division
Housing and Environmental
Regulation Administration
Department of Consumer and
Regulatory Affairs
505 North Potomac Building
614 H St., NW
Washington, DC 20001
202/767-7370

FLORIDA
Department of Environmental
Regulation
Twin Towers Building
2600 Blair Stone Rd.
Tallahassee, FL 32301
904/488-4805

GEORGIA
Environmental Protection
Division
Department of Natural
Resources
825 Trinity-Washington Bldg.
270 Washington St., SW
Atlanta, GA 30334
404/656-4713

HAWAII
Office of Environmental
Quality Control
550 Halekauwila St.
Honolulu, HI 96813
808/548-6915

IDAHO
Division of Environment
Department of Health
and Welfare
Towers Bldg.
450 W. State St.
Boise, ID 83720
208/334-4059

ILLINOIS
Environmental Protection
Agency
220 Churchill Rd.
Springfield, IL 62706
217/782-3397

INDIANA
Environmental Management
Board
State Board of Health
Health Bldg.
1330 W. Michigan St.
Indianapolis, IN 46206
317/633-8404

IOWA
Department of Water, Air,
and Waste Management
Henry A. Wallace Bldg.
900 E. Grand Ave.
Des Moines, IA 50319
515/281-8854

KANSAS
Division of Environment
Department of Health and
Environment
Bldg. 740, Forbes Field
Topeka, KS 66620
913/862-9360, Ext. 283

KENTUCKY
Department of Environment
Natural Resources and
Environmental Protection
Cabinet
Ash Bldg., 18 Reilly Rd.
Frankfort, KY 40601
502/564-2150

## Exhibit 3-1
## (continued)

LOUISIANA
Department of Environmental Quality
700 State Land and Natural Resouces Bldg.
625 N. 4th St.
P.O. Box 44066
Baton Rouge, LA 70804
504/342-1265

MAINE
Department of Environmental Protection
Ray Bldg., AMHI Complex
Hospital St.
Mail to: State House, Station 17
Augusta, ME 04333
207/289-2811

MARYLAND
Maryland Environmental Service
Department of Natural Resources
60 West St.
Annapolis, MD 21401
301/269-3351

MASSACHUSETTS
Executive Office of Environmental Affairs
Leverett Saltonstall State
Office Bldg.
100 Cambridge St.
Boston, MA 02202
617/727-9800

MICHIGAN
Department of Natural Resources
Stevens T. Mason Bldg.
7th Floor
P.O. Box 30028
Lansing, MI 48909
517/373-2329

MINNESOTA
Environmental Quality Board
100 Capitol Square Bldg.
550 Cedar St.
St. Paul, MN 55101
612/296-2603

MISSISSIPPI
Bureau of Pollution Control
Department of Natural Resources
Southport Mall
Hwy. 80-W at Ellis Ave.
P.O. Box 10385
Jackson, MS 39209
601/961-5171

MISSOURI
Division of Environmental Quality
Department of Natural Resources
1915 Southridge Dr.
P.O. Box 1368
Jefferson City, MO 65102
314/751-3241

MONTANA
Environmental Sciences Division
Department of Health and Environmental Sciences
W. F. Cogswell Bldg.
Lockey St.
Helena, MT 59620
406/444-3948

NEBRASKA
Department of Environmental Control
State Office Bldg.
301 Centennial Mall, S.
P.O. Box 94877
Lincoln, NE 68509-4877
402/471-2186

NEVADA
Division of Environmental Protection
Department of Conservation and Natural Resources
221 Nye Bldg.
201 S. Fall St.
Capitol Complex
Carson City, NV 89710
702/885-4670

NEW HAMPSHIRE
Environmental Protection Division
Office of the Attorney General
State House Annex
25 Capitol St.
Concord, NH 03301
603/271-3679

NEW JERSEY
Department of Environmental Protection
John Fitch Plz.
P.O. Box 1390
Trenton, NJ 08625
609/292-2885

NEW MEXICO
Environmental Improvement Division
Health and Environment Department
Crown State Office Bldg.
725 St. Michael's Dr.
P.O. Box 968
Santa Fe, NM 87504-0968
503/984-0020, Ext. 200

NEW YORK
Department of Environmental Conservation
50 Wolf Rd.
Albany, NY 12233-0001
518/457-3446

## Exhibit 3-1
(continued)

NORTH CAROLINA
Division of Environmental Management
Department of Natural Resources and Community Development
Archdale Bldg.
512 N. Salisbury St.
P.O. Box 27687
Raleigh, NC 27611
919/733-7015

NORTH DAKOTA
Environmental Health Section
Department of Health
102 Missouri Office Bldg.
1200 Missouri Ave.
Bismarck, ND 58501
701/224-2374

OHIO
Ohio Environmental Protection Agency
Seneca Towers
361 E. Broad St.
P.O. Box 1049
Columbus, OH 43216
614/466-8318

OKLAHOMA
Department of Pollution Control
1000 N.E. 10th St.
P.O. Box 53504
Oklahoma City, OK 73152
405/271-4677

OREGON
Department of Environmental Quality
Yeon Bldg.
522 S.W. 5th Ave.
P.O. Box 1760
Portland, OR 97207
503/229-5696

PENNSYLVANIA
Department of Environmental Resources
Fulton Bank Bldg., 9th Fl.
200 N. 3rd St.
P.O. Box 2063
Harrisburg, PA 17105
717/787-2814

RHODE ISLAND
Department of Environmental Management
83 Park St.
Providence, RI 02903
401/277-2771

SOUTH CAROLINA
Division of Environmental Quality Control
Department of Health and Environmental Control
415 J. Marion Sims Bldg.
2600 Bull St.
Columbus, SC 29201
803/758-5450

SOUTH DAKOTA
Department of Water and Natural Resources
Joe Foss Bldg.
523 E. Capitol Ave.
Pierre, SD 57501
605/773-3151

TENNESSEE
Bureau of Environment
Department of Health and Environment
TERRA Bldg.
150 9th Ave., N.
Nashville, TN 37203
615/741-3657

TEXAS
Environmental Protection Division
Office of the Attorney General
Executive Office Bldg.
411 W. 13th St.
P.O. Box 12548, Capitol Sta.
Austin, TX 78711
512/475-1101

UTAH
Division of Environmental Health
Department of Health
Social Services Bldg.
150 W. North Temple St.
P.O. Box 2500
Salt Lake City, UT 84110-2500
801/533-6121

VERMONT
Agency of Environmental Conservation
Heritage II Complex
79 River St.
Montpelier, VT 05602
802/828-3139

VIRGINIA
Council on the Environment
903 Ninth St. Office Bldg.
9th and Grace Sts.
Richmond, VA 23219
804/786-4500

WASHINGTON
Washington Department of Ecology
St. Martin's College
Mail Stop PV-11
Olympia, WA 98504
206/459-6168

WEST VIRGINIA
Department of Natural Resources
669 State Office Bldg. 3
1800 Washington St., E.
Charleston, WV 25305
304/348-2754

WISCONSIN
Department of Natural Resources
General Executive Facility II
101 S. Webster St.
P.O. Box 7921
Madison, WI 53707
608/266-2121

**Exhibit 3-1**
**(continued)**

WYOMING
Department of Environmental
Quality
Herschler Bldg., 4th Fl.
122 W. 25th St.
Cheyenne, WY 82002
307/777-7938

AMERICAN SAMOA
Environmental Quality
Commission
Office of the Governor
Pago Pago, AS 96799
Country Code 684/633-4116
and 633-4398

GUAM
Guam Environmental Protection
Agency
P.O. Box 2950
Agana, GU 96910
Country Code 671/646-8863
8864, and 8865

PUERTO RICO
Environmental Quality Board
204 Del Parque St.
P.O. Box 11488
Santurce, PR 00910
809/725-8898 and 723-1617

VIRGIN ISLANDS
Division of Natural Resources
Management
Department of Conservation
and Cultural Affairs
P.O. Box 4340
Charlotte Amalie,
St. Thomas, VI 00801
809/774-3320

The maximum duration for storing wastes onsite is 90 days without a permit or without having interim status, provided that the stored wastes meet the RCRA requirements for containing and labeling. Storage duration beyond 90 days alters the status of the controller from a generator of hazardous waste to an operator of a storage facility. Such a change in status, subjects the operator to compliance with RCRA requirements stated in 40 CFR Parts 264 and 265. A final concern is that, during dismantling, the storage area will need to be sampled (e.g., soil sampling) to determine that no releases of hazardous substances occurred during storage.

Questions on the interpretation of the requirements for storing and handling hazardous substances can be directed to the **RCRA Hotline (1/800/424-9346).**

Provided below is an outline of the suggested procedures for disposal of investigation-derived wastes.

- 1. Determine whether or not investigation derived wastes will be generated during the project. If yes, obtain RCRA EPA Notification of Hazardous Waste Activity Form (Form No. 8700-12). If no, note the decision in the work plan.
- 2. Obtain a RCRA generator provisional number from the EPA Remedial Project Manager (RPM).
- 3. Fill out the provisional number questionnaire and submit it to the EPA RPM.
- 4. Contact waste transporters and disposers to request bids for their services; obtain necessary documentation required by a company for those services. (All companies require the filing of some type of waste data sheet.) A bid will not be awarded until a waste characterization, including data, is provided to the transporter / disposer. These forms can be found in the *Hazardous Waste Services Directing: Transportation, Disposal Sites, Laboratories, and Consultants* published by J.J. Keller Associates (414/722-2848).
- 5. Obtain necessary state / federal shipping and disposal manifest forms. (A manifest is required from the state where the waste originated.)
- 6. Conduct field activities.
- 7. Sample and characterize waste. This step includes all RCRA parameters plus special analyses such as TCDD.
- 8. Receive analysis from laboratory.
- 9. Complete waste data sheets, and submit them to potential transporters and disposal facilities.
- 10. Receive bids for transportation and disposal activities.
- 11. Prepare EPA Form 8700-12, including waste characterization data for sign off by designated EPA official. (**Note:** Materials generated are considered to be EPA wastes, and an EPA employee must sign off on all paperwork.)
- 12. Prepare state and federal shipping and disposal manifest forms for signature by EPA personnel.
- 13. Award subcontract for waste transportation and disposal.

### 3.2.7 Region-Specific Variances

No region-specific variances have been identified; however, all future determined variances will be incorporated within subsequent revisions of this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPMs for full details on current regional practices and requirements.

### 3.2.8 Information Sources

Resource Conservation and Recovery Act of 1976.

## 3.3 ORGANIZATION OF THE FIELD TEAM

### 3.3.1 Scope and Purpose

The objective of this subsection is to provide the roles and responsibilities of field team members who conduct remedial response activities at hazardous waste sites.

### 3.3.2 Definitions

None.

### 3.3.3 Applicability

The primary function of the field investigation team is to gather information according to the approved work plan. These guidelines describe the components and duties of team members, and suggest the numbers of members that are necessary for the field team to safely meet the stated goals of the investigation. These guidelines are applicable to field work involving hazardous waste disposal sites.

### 3.3.4 Responsibilities

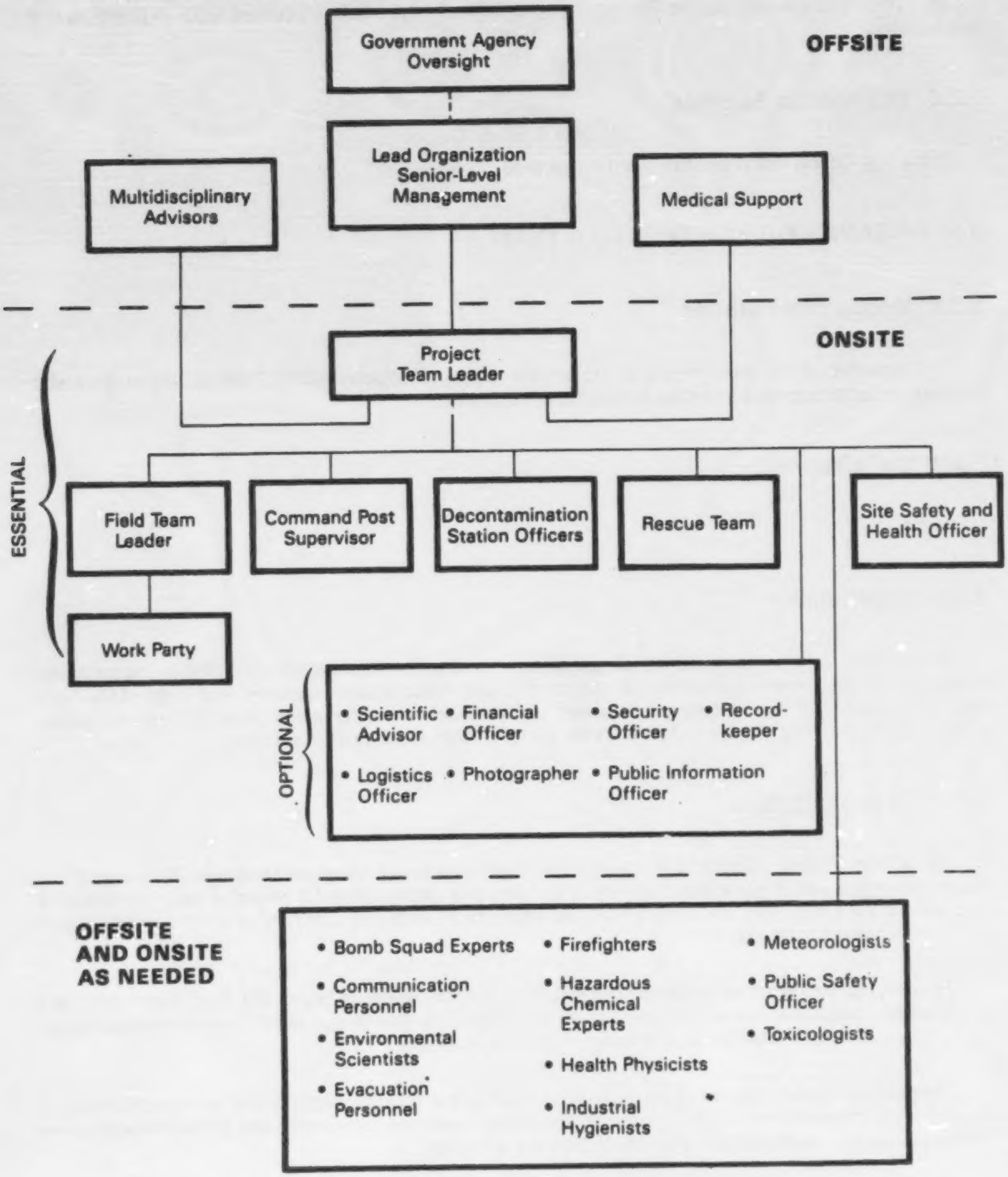
The NIOSH / OSHA / USCG / EPA *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities* presents a generalized approach to personnel organization for remedial response activities (see Exhibit 3-2 taken from that publication) and provides an excellent summary of the responsibilities of each of the named positions.

Typically, at least eight roles may be required for a field investigation team: SM, field team leader, site safety officer, personnel decontamination station operator / equipment specialist, communications supervisor, initial entry party, work party, and emergency response team.

The number of roles needed at each site is dictated by the potential hazards and the specific needs of the site. Dual role assignments may be acceptable when hazardous substances and physical conditions at a site are well documented and the nature of the work is limited.

Exhibit 3-2

## GENERALIZED APPROACH TO PERSONNEL ORGANIZATION FOR SITE INVESTIGATION AND RESPONSE


Government Agency Oversight
OFFSITE
Multidisciplinary Advisors
Lead Organization Senior-Level Management
Medical Support
ONSITE
Project Team Leader
ESSENTIAL
Field Team Leader
Command Post Supervisor
Decontamination Station Officers
Rescue Team
Site Safety and Health Officer
Work Party
OPTIONAL
• Scientific Advisor
• Financial Officer
• Security Officer
• Record-keeper
• Logistics Officer
• Photographer
• Public Information Officer
OFFSITE AND ONSITE AS NEEDED
• Bomb Squad Experts
• Communication Personnel
• Environmental Scientists
• Evacuation Personnel
• Firefighters
• Hazardous Chemical Experts
• Health Physicists
• Industrial Hygienists
• Meteorologists
• Public Safety Officer
• Toxicologists

### 3.3.4.1 Site Manager

The SM is responsible for the following:

- All the team does or fails to do
- Preparing and organizing project work
- Selecting team personnel and briefing them on specific assignments
- Coordinating with the EPA RPM, who is responsible for obtaining the owner's permission to enter the site
- Coordinating with the field team leader to complete the work plan
- Completing final reports and preparing the evidentiary file
- Establishing safety and equipment requirements that are to be met, and monitoring compliance with those requirements
- Coordinating with the lead agency
- Assisting in quality assurance efforts

Some of these responsibilities may be delegated to the field team leader and the site safety coordinator.

### 3.3.4.2 Field Team Leader

The field team leader is responsible for the overall operation and safety of the field team. As mentioned earlier, this role can be filled by the SM or the designated representative. The field team leader may join the work party in the exclusion zone. The field team leader is responsible for the following:

- Execution of the site work plan
- Safety procedure compliance through coordination with the site safety officer
- Field operations management including coordination with laboratories and subcontractors
- Community relations, typically through state and federal liaison officials
- Site control
- Compliance of field documentation and sampling methods with evidence collection procedures

### 3.3.4.3 Site Safety Officer

The site safety officer is responsible for safety procedures and operations at the site. The site safety officer is responsible to whoever is responsible for safety in the organization rather than to the field team leader or SM. This reporting system provides for two separate lines of authority, thereby allowing decisions based on safety to be represented on an equal basis with decisions based on the pressures for accomplishing the investigation according to schedule.

The site safety officer either remains on the clean side of the exclusion area while monitoring the work party and site activities or may accompany the downrange team to supervise hazardous work. The site safety officer is also responsible for the following:

- Determining of the level of personal protection required
- Updating equipment or procedures based on new information gathered during the site inspection
- Changing the levels of protection based on site observations (Subsection 3.3.4)
- Monitoring compliance with the safety requirements
- Stopping work as required to protect personal worker safety or where noncompliance with safety requirements is found
- Determining and posting emergency telephone numbers (including poison control centers) and routes to capable medical facilities; arranging for emergency transportation to medical facilities
- In conjunction with the SM, notifying local public emergency officers (i.e., police and fire department) of the nature of the team's operations and coordinating the team's contingency plan with that of the local authorities
- Informing personnel other than team members who want access to the potential hazards of the site
- Entering the exclusion area in emergencies when at least one other member of the field team is available to stay behind and notify emergency services (or after the emergency services have been notified)
- Examining work party members for symptoms of exposure or stress
- Determining that each team member has been given the proper medical clearance by a qualified medical consultant; monitoring team members to determine compliance with the applicable physical requirements as stipulated in the health and safety program
- Maintaining communications and line-of sight contact with the work party
- Providing emergency medical care and first aid as necessary at the site

### 3.3.4.4 Personnel Decontamination Station Operator / Equipment Specialist

The personnel decontamination station (PDS) operator / equipment specialist functions in two roles that do not require concurrent attention. The equipment specialist role requires the following:

- Determining that equipment is properly maintained and operational
- Inspecting equipment before and after use
- Obtaining the required equipment before arriving at work site
- Decontaminating personnel, samples, and equipment that return from the exclusion area

The role of PDS operator/ equipment specialist includes the following responsibilities:

- Designing and setting up the PDS
- Preparing the necessary decontamination solutions so that chemical contamination is not transported into the clean area by equipment, samples, protective clothing, or personnel
- Managing the mechanics of removing contaminated clothing from the work party
- Properly disposing of discarded contaminated clothing and decontamination solutions

### 3.3.4.5 Communications Supervisor

The communications supervisor functions as the clearinghouse for communications. This person does not enter the exclusion area to assist the work party. Should an emergency arise, the communications supervisor notifies emergency support personnel by phone, radio, or some other communication device to respond to the situation. Depending on the team size and the nature of the emergency, the communications supervisor may be needed to assist the site safety officer in effecting a rescue. Usually, the communications supervisor assists the PDS operator / equipment specialist in operating the PDS during an emergency and the site safety officer in taking emergency medical measures. The field team leader may assume the position of communications supervisor.

The communications supervisor is also responsible for the following:

- Maintaining a log of communications and site activities, such as duration of work periods with respirators or movement of personnel and equipment, onto and off the site
- Assisting the site safety officer in sustaining communication and line-of-sight contact with the work party
- Maintaining good community relations in the absence of the field team leader, usually by referring questions to the appropriate head agency liaison officer
- Assisting the site safety officer and PDS operator/equipment specialist as required

The communications supervisor may also be responsible for logging and packaging for transport, the samples taken by the work party. This person also maintains a weather watch, and provides security for the emergency response vehicle and other equipment.

### 3.3.4.6 Initial Entry Party

The initial entry party enters the site first, employing specialized instrumentation to characterize site hazards. To become familiar with the conditions and dangers associated with the site, the field team leader should usually be a part of the initial entry party. The major purpose of this team is to measure existing hazards and to survey the site to ascertain if the level of personal protection determined from preliminary assessment, site inspection, or site screening study must be adjusted.

The initial entry party can consist of as few as two people (using the "buddy system"), if a nonsparking cart or other device is used to transport all the instrumentation. Three or four people are able to do the job more efficiently.

### 3.3.4.7 Work Party

The work party performs the onsite tasks necessary to fulfill the objectives of the investigation (e.g., obtaining samples or determining locations for monitoring wells). No team member should enter or exit the exclusion area alone. The work party consists of a minimum of two individuals, and any work party should follow the buddy system. Aside from the safety considerations, it is much easier for two persons dressed in protective clothing to perform such tasks as notetaking, photographing and sampling.

The number of individuals in the work party varies. Often, several teams may be working simultaneously at several different sampling efforts. In cases where a number of activities are taking place simultaneously or where activities are widely separated, the site safety officer may be supplemented with several assistants assigned to each of the smaller work teams. Depending on the nature of the hazards onsite, the work team safety officer may perform concurrent duties (photography, air monitoring, headspace analysis, sample logging) that would not interfere with the primary duty of maintaining safety.

In cases of multiple or widely separated work teams, a means of communication among the teams, the site safety officer, and the field team leader is vital.

### 3.3.4.8 Emergency Response Team

Some means of providing emergency assistance to workers in the exclusion zone must be established for every site. Most often, the site safety officer has that responsibility. Extensive assignments requiring long hours and large work parties may necessitate the use of a standby emergency response team. Members of the emergency response team are "half-dressed" in the appropriate protective gear so that they can quickly enter the exclusion area in an emergency. This team is particularly valuable at sites where protective equipment produces stress and heat loads on the work party and where the rotation of workers provides a rested group of workers able to respond to the emergency without increasing the team size.

## 3.3.5 Records

Records normally kept for field activities are identified in other sections of this manual. For details, see the following sections:

| | |
|---|---|
| Section 4 | Sample Control, Including Chain of Custody |
| Section 5 | Laboratory Interface |
| Section 17 | Document Control |

## 3.3.6 Procedures

The different guidelines that exist for organizing field operations are based generally on the size of the field team used.

Team size depends on site organization, levels of protection, work objectives, and site hazards. Team members can always be added according to the roles required.

### 3.3.6.1 Two-Person Team

The two-person team is the minimum for a hazardous-substance site investigation, and the team's capabilities are very limited. Such a team should never enter an uncharacterized hazardous-substance site. The two-person team is best suited for offsite surveys and inspections or for obtaining environmental (nonhazardous, offsite) samples. Verifying accuracy of aerial photographs by ground surveys, inspecting files, or interviewing can all be accomplished by the two-person team. The two-person team can also conduct RCRA inspections at facilities that have an OSHA-approved safety program.

### 3.3.6.2 Three-Person Team

The three-person team is recommended for sites requiring Level C (air purifying respirators) protection and, in some cases, at sites requiring Level B (supplied-air respirator) protection. (Levels of protection are discussed in the NIOSH / OSHA / USCG / EPA guidance manual and are set forth in the OSHA 29 CFR 1910.120 regulations.) This team is composed of a field team leader; an individual fulfilling the combined functions of PDS operator / equipment specialist, site safety officer, and communications supervisor; and another individual (buddy) to enter the site with the field team leader.

The three-person team is used where extensive PDS procedures are not required and where the likelihood of needing emergency rescue is low. This field team is best used where the primary objective is to map, photograph or inventory.

Considerable care and thought are necessary before a three-person team is employed on a site, because each individual has numerous responsibilities. In the event of an accident, the third member does not enter the site to offer emergency assistance until outside assistance has been summoned; even then, entry should be made only when absolutely necessary.

### 3.3.6.3 Four-Person Team

Most short-term Level B operations can be conducted with a four-person team. These operations would include work on active sites where facility personnel are present or on inactive sites with potentially IDLH (Immediately Dangerous to Life and Health) atmospheres. The objective of a four-person team at a site requiring Level B protection might include limited sampling of ponds, soils, or open containers and inspections at sites known for poor housekeeping (i.e., sites with a history of spills, leaks, or other accidents).

The team consists of the standard two-person work party, a combination site safety officer and PDS operator / equipment specialist, and a communications supervisor who may assist in the PDS operation. Because life-threatening hazards are assumed or known to be present at a Level B site, it is essential that all personnel be fully acquainted with their duties. During an emergency, the communications supervisor stays in the support area to maintain communication while the site safety officer / PDS operator / equipment specialist enters the exclusion area to aid the work party. Once the work party is in the contamination reduction area, the command post supervisor can offer assistance on the PDS or provide fresh equipment from the support area. During the work in the exclusion area, team members may rotate individual assignments.

### 3.3.6.4 Five-Person Team

The five-person team is the typical minimum size for most Level A and Level B operations or for operations when known percutaneous hazards exist or when there is an absence of historical information. The site hazards that necessitate Level A protection, combined with the limitations and stresses placed on personnel by wearing Level A protection, require a full-time PDS operator / equipment specialist who can also serve in emergency response. In the event of a serious emergency such as a fire, explosion, or acutely toxic release, both the site safety officer and the PDS operator / equipment specialist may need to enter the exclusion area dressed in Level A gear. The communications supervisor remains in the support area to direct outside help to the site and then to assume the functions of PDS operator / equipment specialist.

#### 3.3.6.5 Teams of Six or More

Certain hazardous-substance site activities may require operations that necessitate larger or alternating work parties and additional support personnel in the contamination reduction area. A seven-person team, for example, employs the basic structure of the five-person team plus an additional work party for alternating work loads. The eight-person team includes an additional PDS operator / equipment specialist to assist in the continuous decontamination tasks that are involved with alternating work parties and to decontaminate and pack samples as they are received.

It is not unusual to employ teams of 12 where such tasks as drum opening, may require three work parties working concurrently. This operation may involve teams to move the drums, open the drums, and sample and reseal them under rigorous safety procedures. Larger teams can be designed with additional work parties and support personnel, to safely gather the site data, and ensure communication and site control.

On some sites, many individuals will be required for concurrent operations, such as building demolition or wastes excavation, that will also entail the use of mobile heavy equipment. It is not feasible to provide a "buddy" to the operators of such equipment. Rather, a number of site safety observers (two usually will suffice) may be established at vantage points (rented scaffolding located onsite is ideal), to observe the equipment operators and the ground-based workers simultaneously. By means of radios or visual and audible signals, the site safety observers can assist in "directing traffic," a particularly important safety procedure where the protective gear interferes with hearing and vision.

### 3.3.7 Region-Specific Variances

In Region VI, the site safety officer for the Field Investigation Team (FIT) cannot downgrade the level of protection without consulting the FIT regional safety coordinator. No other region-specific variances have been identified. All subsequent variances will be incorporated within Revision 01 of this compendium. Because information on variances may become dated rapidly, users should contact the regional EPA RPMs for full details on current regional practices and requirements. Regional variations of team organizations should be established by coordinating the work plan with the EPA RPM.

### 3.3.8 Information Sources

Office of Safety and Health Administration, 29 CFR 1910.120. "Interim Final Rule for Hazardous Waste Operations and Emergency Response." 19 December 1986.

U.S. Environmental Protection Agency. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities*. Developed by NIOSH / OSHA / USCG / EPA. October 1985.

U.S. Environmental Protection Agency. "Standard Operating Safety Guides." Memorandum from William Hedeman, Jr. 19 November 1984.

## 3.4 DECONTAMINATION

### 3.4.1 Scope and Purpose

Personnel conducting activities that involve hazardous substances may have their personal protective gear contaminated by those substances through the course of the work effort. In addition, equipment may become contaminated. Since such contamination is not always easily discernible, it is necessary to assume that all personnel and equipment working in the area (where the presence of such substances is known or suspected) have been contaminated. Effective decontamination procedures are implemented to minimize the potential for cross contamination (the transfer of contaminants, usually from one sample to another, by improperly decontaminated sampling equipment, containers, or devices such as drill rigs); offsite contaminant migration (the transfer of contaminants to areas outside the exclusion zone, usually by improperly decontaminated equipment); or personnel exposure from improperly decontaminated protective gear.

The subsections below present a general discussion of decontamination issues. Detailed guidance on methods, techniques, procedures, equipment, and solutions exist in the documents shown in Subsection 3.4.7. The SM and site safety officer should study and reference these documents when preparing the decontamination procedures.

### 3.4.2 Definitions

**Decontamination**
The process of neutralization, washing, rinsing, and removing exposed outer surfaces of equipment and personal protective clothing to minimize the potential for contamination migration.

**Cross Contamination**
The transfer of contaminants from their known or suspected location into a noncontaminated area; a term usually applied to sampling activities.

### 3.4.3 Applicability

The procedures in this subsection apply to activities where the potential exists for exposures of personnel and equipment to hazardous substances.

### 3.4.4 Responsibilities

The SM is responsible for determining the type of decontamination facility to be used onsite, the solutions to be employed, and the methodologies to be used in determining the effectiveness of the decontamination approach. The SM is assisted by the field team leader and site safety officer. Onsite, the field team leader is responsible for implementing the decontamination plan by providing materials and staff members. The site safety officer oversees the decontamination process and provides verification of the effectiveness of the procedures. The decontamination plan should be presented or referenced in the work plan and Quality Assurance Project Plan (QAPjP).

### 3.4.5 Records

The QAPjP and work plan document the decontamination approach. The use of equipment cleaning blanks, decontamination rinse blanks, and other quality control procedures serves to document the effectiveness of the cleaning before and the decontamination after working onsite. The site safety officer typically furnishes documentation of equipment decontamination for those items leaving the site (see Exhibit 3-3). Such documentation is typically required by EPA for government-owned equipment. In some instances, such as decontaminating a drill rig normally used by a subcontractor for water well installation, the SM may need to arrange for laboratory testing of wipe samples before documenting the "cleanliness" of a piece of equipment.

### 3.4.6 Procedures

Numerous procedures are used in decontaminating people and things. The most effective procedure is contamination avoidance, that is, the use of procedures or materials to minimize or eliminate the potential for contact with contaminants. Personal protection gear and standard operating procedures are used to protect workers; other techniques include encasing instruments and equipment in disposable outer wrappings (plastic sheeting), using disposable sampling devices, or isolating the contaminants.

Decontaminating procedures include flushing with water or other solvents; using pressure or steam jets; heating, flaming, or baking items; scraping, rubbing, or grinding away; or, most simply, disposing of the item after determining that the cost in time and staff necessary for decontamination is not acceptable, or that decontamination would not be effective. Several documents offer detailed guidance on procedures (see below).

### 3.4.7 Information Sources

Chapter 10, Decontamination, of the *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities* developed by NIOSH / OSHA / USCG / EPA. October 1985.

U.S. Environmental Protection Agency. "Decontamination Techniques for Mobile Response Equint Used at Waste Sites (State-of-the-Art Survey)." EPA/600/52-85/105. January 1986.

U.S. Environmental Protection Agency. *Guide for Decontaminating Buildings, Structures, and Equipment at Superfund Sites.* EPA/600/2 85/028. March 1985.

U.S. Environmental Protection Agency. *Field Standard Operating Procedures #7 Decontamination of Response Personnel.* January 1985.

U.S. Environmental Protection Agency. "Standard Operating Safety Guides." November 1984.

## Exhibit 3-3
## DOCUMENTATION OF EQUIPMENT DECONTAMINATION

Contract No: ____________________
Work Assignment: ____________________
Project No: ____________________
Site Manager: ____________________
Firm: ____________________
Phone No: ____________________
Site Name/Location: ____________________

The following items of (government-owned) (corporate-owned) (rental) equipment have been decontaminated following the procedures detailed in the Site Safety Plan dated __________, (as modified on __________). Additional information on the procedures used is contained in (list site logs, work plans, photographs, etc. ____________________).

| Equipment Nomenclature | Manufacturer's or EPA Serial Number | Dates of Use | Date of Decon. |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

SIGNED:

____________________ DATE: ____________________
Site Safety Coordinator

____________________ DATE: ____________________
Site Manager/Field Team Leader

NOTE: Attach tags to the decontaminated EPA-owned equipment showing the date of decontamination, the SSC's initials, and the work assignment/project number(s).

## 3.5 GENERAL HEALTH AND SAFETY CONSIDERATIONS

### 3.5.1 Scope and Purpose

Field activities at hazardous waste sites are conducted according to detailed health and safety procedures. These procedures are developed in accordance with the implementing regulations for Public Law 91-596, the Occupational Health and Safety Act of 1970, contained in 29 CFR Part II (29 CFR 1910.120, 1910.126, 1910.134, 1910.141, 1910.165, and 1910.1200, among others). Following standardized health and safety procedures will reduce the possibility of accidents or excess exposures of onsite workers to hazardous materials while allowing field activities to be carried out in a uniform manner. The purpose of this subsection is to out line several standard health and safety field procedures that are normally used in the conduct of remedial response activities. Site specific health and safety requirements are detailed in health and safety plans developed for each onsite visit. The general procedures to meet health and safety requirements are described below.

### 3.5.2 Definitions

None.

### 3.5.3 Applicability

This procedure is applicable to onsite activities that are carried out at hazardous waste sites by field personnel.

### 3.5.4 Responsibilities

The Site Managers are ultimately responsible for the health and safety of workers onsite. They are assisted by the site safety officer.

The site safety officer is responsible for developing safe work procedures for onsite and offsite assessment and for monitoring compliance with those procedures. The site safety officer obtains and implements the site safety plan.

The field team leader is responsible for the overall operation of the field team. The field team leader works with the site safety officer to conduct operations in compliance with the site safety plan.

Field team members are responsible for conducting tasks in accordance with the site safety plan developed for the activity. Field team members are also responsible for reporting to the field team leader any information that may have an impact on the health and safety of the operation.

### 3.5.5 Records

The measurements and observations mentioned in this subsection are documented in the project logbook. A site safety plan must be prepared for each field activity and must be available for review by onsite personnel.

## 3.5.6 Procedures

### 3.5.6.1 Site Safety Plan

A site safety plan (SSP) must be prepared by a qualified safety person for each field investigation activity. Review and approval by a different, equally qualified, safety staff member is typically required. For remedial action at hazardous waste sites, safety plans can be developed simultaneously with general operation plans and implemented when remedial actions begin. Emergency response situations may require verbal safety instructions and the use of standard operating safety procedures, until specific safety protocols can be written. For any remedial response activities, the SSP must include health and safety considerations for all activities required at the scene. The SSP must be reviewed and updated whenever additional site data are received, onsite personnel change, the level of protection used onsite is upgraded or downgraded, or site operations differ from those covered by the existing plan.

The field team members shall be thoroughly trained in the use of safety plans. The plan will be prepared under the direction of the site safety officer by persons knowledgeable with the site conditions and safety requirements. The SM and a designated health and safety staff member must approve the plan.

**Minimum Requirements:** Paragraph (i) of 29 CFR 1910.120 requires employees to develop a site safety and health plan that, as a minimum, addresses the following:

- Evaluate the risks associated with the site and with each operation conducted. A scope of work will be included that summarizes the tasks required to perform each operation safely.
- Identify key personnel and alternates responsible for both site safety and remedial response operations.
- Address the levels of protective equipment to be worn by personnel during each site activity. Also, include a decision logic for upgrading or downgrading the level of protection.
- Designate work areas (exclusion zone, contamination reduction zone, and support zone), boundaries, size of zones, distance between zones, and access control points into each zone.
- Establish decontamination procedures for personnel and equipment.
- Determine the number of personnel and equipment needed in the work zones during initial entries and subsequent operations.
- Establish site emergency procedures (e.g., escape routes; signals for evacuating work parties; internal, external, and emergency communications; and procedures for fire and explosions). Emergency phone numbers (fire department, police department, hospital, ambulance, poison control center, and medical consultant) must appear on an emergency reference page.
- Implement a program and make arrangements with the nearest medical facility (and medical life squad unit) for emergency medical care of routine injuries and toxicological problems. A map showing the route from the site to the medical facility must be included in the plan.
- Document individual training requirements for the available use of protective gear and field instruments and for the performance of particular tasks.
- Identify known or suspected contaminants onsite, location and concentration of contaminants, hazards associated with each contaminant (including toxicity and health effects), and action levels that would require upgrading the level of personal protective equipment.

- Describe the procedures and equipment required to monitor the work area for potentially hazardous materials. Detail the necessary records associated with the monitoring program.

- Consider weather and other conditions that may affect the health and safety of personnel during site operations.

- Implement control procedures to prevent access to the site by unauthorized personnel.

- Describe medical surveillance requirements for each operation.

- Provide background information to familiarize the field team with the site history, current status, physical features, disposal practices, past monitoring data, and community/worker health complaints.

### 3.5.6.2 General Safety Practices

**Personnel Precautions:** The following are standard personnel safety precautions:

- Eating, drinking, chewing gum or tobacco, smoking, or any practice that increases the probability of hand-to-mouth transfer and ingestion of material, is prohibited in any area designated as contaminated.

- Hands and face must be thoroughly washed upon leaving the work area and before eating, drinking, or any other activities.

- Whenever decontamination procedures for outer garments are in effect, the entire body shall be thoroughly washed as soon as possible after the protective garment is removed.

- No excessive facial hair, which interferes with a satisfactory fit of the mask-to-face seal, is allowed on personnel required to wear respiratory protective equipment.

- Contact with contaminated surfaces or with surfaces suspected of being contaminated shall be avoided. Whenever possible, a person shall not walk through puddles, mud, and other discolored surfaces; kneel on ground; or lean, sit, or place equipment on drums, containers, vehicles, or the ground.

- Medicine and alcohol can potentiate the effects from exposure to toxic chemicals. Prescribed drugs shall not be taken by personnel on response operations, if there is likelihood of such potentiation.

- Personnel and equipment in the contaminated area shall be kept to a minimum, consistent with effective site operations.

- Work areas for various operational activities must be established.

- Procedures for leaving a contaminated area must be planned and implemented before personnel go to the site. Work areas and decontamination procedures must be established on the basis of prevailing site conditions.

- Contact lenses shall not be worn by individuals required to wear respiratory protection or required to enter a potentially contaminated area.

**Weather:** Adverse weather conditions are important considerations in planning and conducting site operations. Hot or cold weather can cause physical discomfort, loss of efficiency, and personal injury. Of particular importance is heat stress resulting when protective clothing decreases natural body ventilation. One or more of the following can be used to reduce heat stress:

- Provide plenty of liquids. To replace body fluids (water and electrolytes) lost because of sweating, use a 0.1 percent saltwater solution, more heavily salted foods, or commercial mixes. Current research indicates commercial mixes high in electrolytes and low in salt are preferable.
- Provide cooling devices to aid natural body ventilation. These devices, however, add weight and their use must be balanced against worker efficiency.
- Install mobile showers or hose-down facilities to reduce body temperature and to cool protective clothing.
- In extremely hot weather, conduct operations in the early morning or the evening.
- Provide adequate shelter to protect personnel against heat (or cold, rain, snow, etc.), which can decrease physical efficiency and increase the probability of accidents.
- In hot weather, rotate shifts of workers as required to manage heat stress; reduce the length of the work period and increase the length of the rest period.
- Maintain good hygienic standards; frequent change of clothing; and daily showering. Clothing should be permitted to dry during rest periods. Persons who notice skin problems should immediately consult medical personnel.

**Heat Stress Monitoring:** For monitoring the body's recuperative ability after exposure to excess heat, several techniques are available as a screening mechanism. Monitoring of personnel who wear impervious clothing typically commences when the ambient temperature is 70°F or above. When temperatures exceed 85°F, workers are monitored for heat stress after every work period, usually 2 hours. The following are two monitoring schemes:

- 1. Heart rate (HR) is measured by the radial pulse for 30 seconds as early as possible in the resting period. The HR at the beginning of the rest period should not exceed 110 beats/minute. If the HR is higher, the next work period is shortened by 10 minutes (or 33 percent), while the length of the rest period stays the same. If the pulse rate is 100 beats/minute at the beginning of the next rest period, the following work cycle is shortened by 33 percent.
- 2. Body temperature is measured orally with a clinical thermometer as early as possible in the resting period. Oral temperature (OT) at the beginning of the rest period should not exceed 99°F. If it does, the next work period is shortened by 10 minutes (or 33 percent), while the length of the rest period stays the same. However, if the OT exceeds 99.7°F at the beginning of the next period, the following work cycle is further shortened by 33 percent. OT is measured again at the end of the rest period to make sure that it has dropped below 99°F. (Since a mercury thermometer requires as long as 5 minutes to register the correct body temperature, the use of digital thermometers should be considered.)

**Effects Of Heat Stress:** If the body's physiological processes fail to maintain a normal body temperature because of excessive heat, a number of physical reactions can occur ranging in degree from mild (such as fatigue, irritability, anxiety, or a decrease in concentration, dexterity, or movement) to fatal. First aid books should be consulted for specific symptoms and treatment.

**Effects of Cold Exposure:** Persons working outdoors in temperatures at or below freezing may be frostbitten. Exposure to extreme cold for a short time may cause severe injury to the surface of the body or result in profound generalized cooling, causing death. Areas of the body that have a high surface-area-to-volume ratio, such as fingers, toes, and ears, are the most susceptible.

Two factors influence the development of a cold injury: ambient temperature and the velocity of the wind. Wind chill is used to describe the chilling effect of moving air in combination with low temperature. For instance, 10°F with a wind of 15 mph is equivalent in chilling effect to still air at -18°F. Charts depicting the wind-chill factor are readily available.

As a general rule, the greatest incremental increase in wind chill occurs when a wind of 5 mph increases to 10 mph. Additionally, water conducts heat 240 times faster than air. Thus, the body cools suddenly when chemical-protective equipment is removed if the clothing underneath is soaked with perspiration.

Local injury resulting from cold is included in the generic term frostbite. There are several degrees of damage.

Systemic hypothermia is caused by exposure to freezing or rapidly dropping temperature. Its symptoms are usually exhibited in five stages: (1) shivering; (2) apathy, listlessness, sleepiness, and (sometimes) rapid cooling of the body to less than 95°F; (3) unconsciousness, glassy stare, slow pulse, and slow respiratory rate; (4) freezing of the extremities; and, finally (5) death.

First aid books should be consulted for symptoms and specific treatments for cold injury.

### 3.5.6.3 Site Survey and Reconnaissance

Before the team enters the site, as much information as possible should be collected concerning the types of hazards, degree of hazards, and risks that may exist. Using available information (shipping manifests, transportation placards, existing records, container labels, etc.) or off site studies, the team will assess the hazards and identify the initial safety requirements.

The team(s) initially entering the site must accomplish one or more of the following objectives:

- Characterize the hazards that exist, or potentially exist, affecting the public health, the environment, and the response personnel.
- Verify existing information and/or obtain data about the incident.
- Evaluate the need for prompt mitigative actions.
- Collect supplemental information to determine the safety requirements for personnel who initially and subsequently enter the site.

**Preliminary Onsite Evaluation:** The initial onsite survey is to determine, on a preliminary basis, hazardous or potentially hazardous conditions. The main effort is to rapidly identify the immediate hazards that may affect the public, the response personnel, and the environment. Of major concern are the real potential dangers – fire, explosion, oxygen deficient atmospheres, radiation, airborne contaminants, or containerized or pooled hazardous substances – that could affect workers during subsequent operations.

**Visual Observations:** While at the site, the initial entry team should make visual observations that would help in evaluating site hazards. Some examples are dead fish or other animals; land features; wind direction; labels on containers indicating explosive, flammable, toxic, or corrosive materials; conditions conducive to splash or contact with unconfined liquids, sludges, or solids; and other general conditions.

**Direct-Reading Instruments:** A variety of toxic air pollutants including organic and inorganic vapors, gases, or particulates can be produced at abandoned waste sites by fires at chemical manufacturing, storage, reprocessing, or formulating facilities or by the inadvertent mixing of chemicals during bulking operations. Direct-reading field instruments will not detect or measure all of these substances. Thus, lack of response should not be interpreted as the complete absence of airborne toxic substances. Verification of zero results can be done only by collecting air samples and analyzing them in a laboratory.

**Priority for Initial Entry Monitoring:** Of immediate concern to initial entry personnel are atmospheric conditions that could affect the immediate safety of these personnel (see Exhibit 3-4). These conditions are airborne toxic substances, combustible gases or vapors, lack of oxygen, and, to a lesser extent, ionizing radiation. Priorities for monitoring these potential hazards should be established after a careful evaluation of conditions.

When the type(s) of material(s) involved in the investigation is identified and its release into the environment suspected or known, the material's chemical or physical properties and the prevailing weather conditions may help determine the order of monitoring. An unknown substance(s) or situation(s) presents a more difficult monitoring problem.

In general, when poorly ventilated spaces (buildings, ships' holds, boxcars, or bulk tanks) are entered, combustible vapors or gases and oxygen-deficient atmospheres shall be monitored first by team members wearing (as a minimum) supplied-air respirators and a high degree of dermal protection. Measurement of toxic gases or vapors and radiation, unless known not to be present, should be the next priority.

For open, well-ventilated areas, combustion gases and oxygen deficiency are lesser hazards and require lower priority. However, areas of lower elevation at the site (such as ditches and gullies) and downwind areas may have combustible gas mixtures, in addition to toxic vapors or gases, and may lack sufficient oxygen to sustain life. Entry teams should approach and monitor whenever possible from the upwind side of an area.

**Periodic Monitoring:** The monitoring surveys made during initial entry to the site are for a preliminary evaluation of atmosphere hazards. In some situations, the information obtained may be sufficient to preclude additional monitoring. A chlorine tank determined to be releasing no chlorine, is one such example. Materials detected during the initial site survey may indicate the need for a more comprehensive evaluation of hazards and analyses for specific components. A program must be established for monitoring, sampling, and evaluating hazards for the duration of site operations. Since site activities and weather conditions change, a continuous program to monitor atmospheric changes must be implemented using a combination of stationary sampling equipment, personnel monitoring devices, and periodic area monitoring with direct reading instruments.

## Exhibit 3-4
## ATMOSPHERIC HAZARD GUIDELINES

| Monitoring Equipment | Hazard | Ambient Level | Action |
|---|---|---|---|
| Combustible Gas Indicator | Explosive atmosphere | LT[a] 10% LEL[b] | Continue investigation. |
| | | 10-20% | Continue onsite monitoring with extreme caution as higher levels are encountered. |
| | | GT[c] 20% LEL | Explosion hazard; withdraw from area immediately. |
| Oxygen Concentration Meter | Oxygen | LT 19.5% | Monitor, wearing self-contained breathing apparatus (SCBA). NOTE: Combustible gas readings are not valid in atmospheres with LT 19.5% oxygen. |
| | | 19.5-25% | Continue investigation with caution. SCBA not needed, based on oxygen content only. |
| | | GT 25.0% | Discontinue inspection; potential fire hazard. Consult specialist. |
| Radiation Survey | Radiation | LT 1 mR/hr | Continue investigation. If radiation is detected above background levels, this signifies the presence of possible radiation sources; at this level, more thorough monitoring is advisable. Consult a health physicist. |
| | Radiation | GT 10 mR/hr | Potential radiation hazard; evacuate site. Continue monitoring only upon the advise of a health physicist. |
| Thermoluminescent Detector (TLD) Badge | Radiation | | All employees shall wear a TLD badge when working on hazardous waste sites and during any response operation. Badges will be analyzed quarterly to determine compliance with federal standards. |
| Colorimetric Tubes | Organic and inorganic vapors/gases | Depends on species | Consult standard reference manuals for air concentration/toxicity data. |
| Photoionization Detectors | Total organic vapors/gases and limited inorganic species | Above background | Consult EPA standard operating procedures. |
| Flame-ionization Detectors | Total organic vapors/gases | Above background | Consult EPA standard operating procedures. |
| | Specific organic vapor/gases | Depends on species | Consult standard reference manuals for air concentrations/toxicity data. |

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[a] LT means less than.

[b] LEL is defined as lower explosive limit.

c GT means greater than.

**Peripheral Monitoring:** Whenever possible, atmospheric hazards in the areas adjacent to the onsite zone are monitored with direct-reading instruments, and air samples should be taken before the initial entry for onsite monitoring. The lack of readings on instruments away from the site does not indicate a lack of hazards onsite. Offsite readings are only another piece of information to assist in the preliminary evaluation.

**Monitoring Instruments:** It is imperative that personnel using monitoring instruments be thoroughly familiar with their use, limitations, and operating characteristics. All instruments have inherent constraints in their ability to detect and/or quantify the hazards for which they were designed. Unless trained personnel use instruments and assess data readout, air hazards can be misinterpreted. In addition, only intrinsically safe instruments shall be used until the absence of combustible gases or vapors can be confirmed.

**Ambient Atmospheric Concentrations:** Any indication of atmospheric hazards (toxic substances, combustible gases, lack of oxygen, radiation, and other specific materials) should be viewed as a sign to proceed with care and deliberation. Readings indicating nonexplosive atmospheres, low concentrations of toxic substances, or other conditions may increase or decrease suddenly, changing the associated risks.

### 3.5.7 Information Sources

U.S. Environmental Protection Agency. "Standard Operating Safety Guides." Memorandum from William Hedeman, Jr. 19 November 1984.

U.S. Environmental Protection Agency. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities.* Developed by NIOSH / OSHA / USCG / EPA. October 1985.

Occupational Safety and Health Administration. "Interim Final Rule for Hazardous Operations and Emergency Response." 29 CFR 1910.120. 19 December 1986.

# SECTION 4

# SAMPLE CONTROL, INCLUDING CHAIN OF CUSTODY

## 4.1 SCOPE AND PURPOSE

This section describes procedures for sample identification and chain of custody. The purpose of these procedures is to maintain the quality of samples during collection, transportation, and storage for analysis. Sample control and chain-of-custody procedures specific to the Contract Laboratory Program (CLP) are presented in the *User's Guide to the Contract Laboratory Program*.

## 4.2 DEFINITIONS

**Sample**
Physical evidence collected for environmental measuring and monitoring. Evidence includes remote-sensing imagery and photographs.

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

## 4.3 APPLICABILITY

When environmental measuring or monitoring data are collected for the Environmental Protection Agency (EPA), workers should refer to the procedures in this section.

## 4.4 RESPONSIBILITIES

The SM or designee is responsible for monitoring compliance with these procedures. In general, it is desirable to appoint one person to be responsible for implementing sample control procedures (i.e., field operations leader). However, each sampler is responsible for the activities described in Subsections 4.5 and 4.6.

## 4.5 RECORDS

The following records are kept:

- Sample identification tags (varies with the EPA region; see Subsection 4.7 and Exhibit 5-7)
- Sample traffic reports (e.g., Special Analytical Services (SAS); see Exhibits 5-2, 5-3, and 5-9)
- Chain-of-custody (COC) forms and records (see Exhibits 5-4, 5-5, and 5-6)
- Receipt-for-samples forms (varies among EPA regions; see Subsection 4.7 and Exhibit 4-3)

- Field Investigation Team (FIT) receipt (for sample forms and field notebooks not serially numbered by the U.S. EPA)
- Field notebooks
- Airbills or bills of lading
- Dioxin analysis forms (as applicable)
- Photographic logs

Subsection 4.6 describes procedures for these records; Subsection 5.1.6 shows completed exhibits of the first three items.

## 4.6 PROCEDURES

Sample identification documents must be prepared to maintain sample identification and chain of custody. The following are sample identification documents:

- Sample identification tags
- Sample traffic reports
- Chain-of-custody records
- Receipt-for-samples forms
- Custody seals
- Field notebooks

These documents are usually numbered (serialized) by EPA. Some varieties of custody seals, field notebooks, or photographic logs may not be serialized.

The following additional forms are used for samples shipped to CLP laboratories:

- Organic traffic reports
- Inorganic traffic reports
- High-hazard traffic reports
- SAS request forms
- Dioxin shipment records (as applicable)

Completed examples of these forms are in Subsection 5.1.6 of this compendium.

The organization's document control officer (designated on exhibits in this subsection as the Regional Document Control Officer or RDCO) or another designated person maintains a supply of the documents listed above, including field note books. The document control officer is responsible for the inventory of serialized documents and the assignment of these documents to specific projects. Unused field documents are usually returned to the document control officer at the end of the field sampling event. The document control officer notes the return of these documents in the serialized document logbook. In some EPA regions, unused field documents are retained by the sampler to whom they were originally assigned for use on future projects. The sampler maintains a personal logbook in which is recorded the final disposition of all relevant field information. Unused, returned documents may be checked out to another project by the RDCO, as needed. A cross reference of serialized field documents is usually maintained for each project in the project files. A sample cross-reference matrix is shown in Exhibit 4-1.

The document control officer orders sample identification tags, receipt-for samples forms, custody seals, and chain-of-custody records from the EPA regional offices. Traffic reports and SAS request forms are obtained through the Sample Management Office (SMO) representative.

Exhibit 4-2 shows how the sample control documents can be integrated into the document control procedures used in an EPA project. The procedures for using each document are discussed below. Subsection 4.7 discusses regional variations; however, because procedures change and vary from region to region, the EPA Regional Sample Coordinating Center (RSCC) should be contacted during the planning of field activities to obtain the most current procedures. Appendix A of the *User's Guide to the CLP* contains a directory of RSCC contacts and telephone numbers.

### 4.6.1 Sample Identification Tags

Sample identification tags (see Exhibit 5-7) are distributed as needed to field workers by the SM (or designated representative). Procedures vary among EPA regions. Generally, the EPA serial numbers are recorded in the project files, the field notebook, and the document control officer's serialized document logbook. Individuals are accountable for each tag assigned to them. A tag is considered to be in an individual's possession until it has been filled out, attached to a sample, and transferred to another individual along with the corresponding chain-of custody record. Sample identification tags are not to be discarded. If tags are lost, voided, or damaged, the facts are noted in the appropriate field notebook, and the SM is notified.

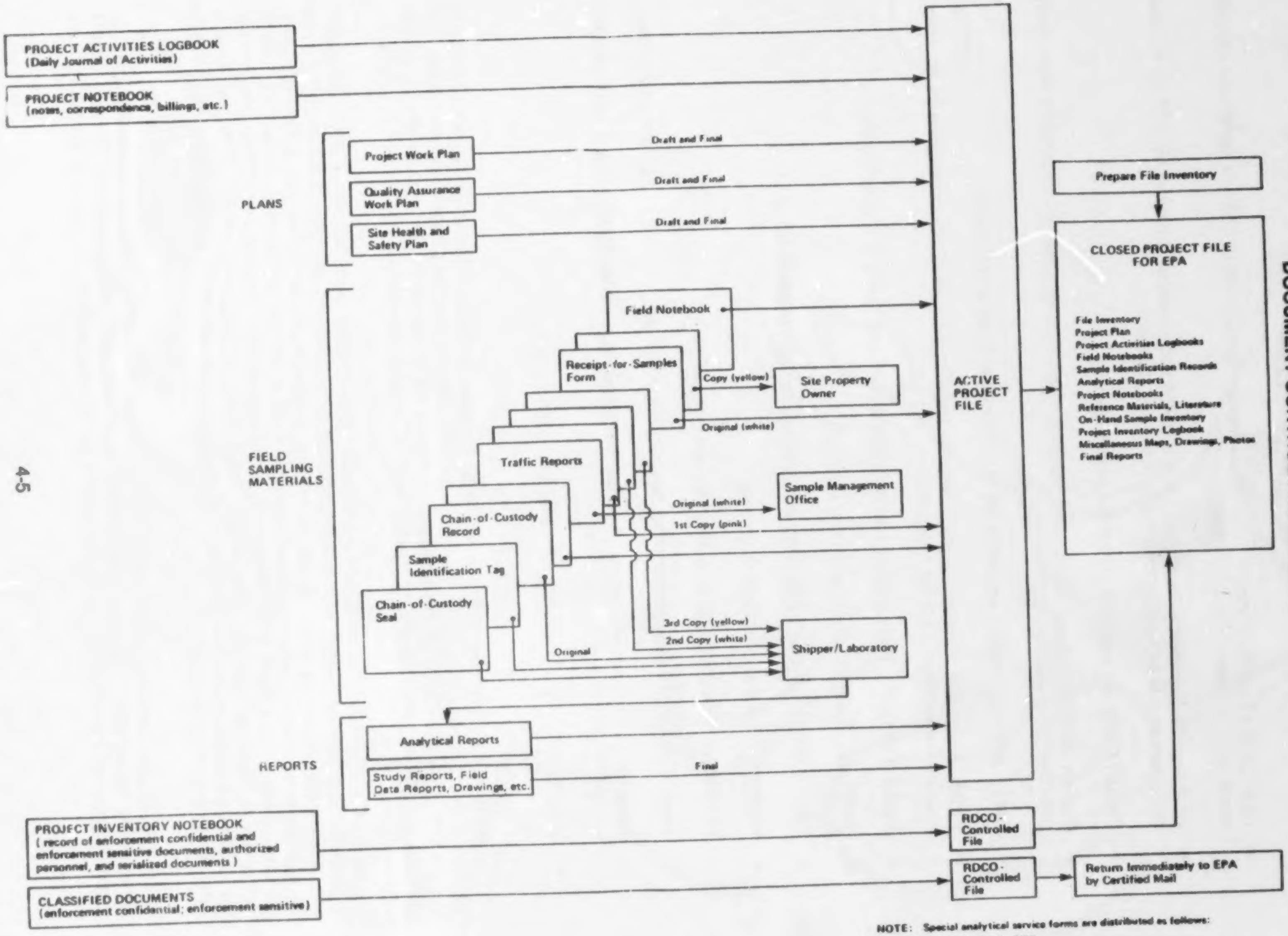
Upon the completion of the field activities, unused sample identification tags are returned to the document control officer, who checks them against the list of assigned serial numbers. Tags attached to those samples that are split with the owner, operator, agent-in-charge, or a government agency are accounted for by recording the serialized tag numbers on the receipt-for-samples form (Exhibit 4-3). Alternatively, the split samples are not tagged but are accounted for on a chain-of-custody form.

Samples are transferred from the sample location to a laboratory or another location for analysis. Before transfer, however, a sample is often separated into fractions, depending on the analysis to be performed. Each portion is preserved in accordance with prescribed procedures (see User's Guide to the CLP and Section 6 of this compendium) and is identified with a separate sample identification tag, which should indicate in the "Remarks" section that the sample is a split sample.

## Exhibit 4-1
## CROSS REFERENCE MATRIX FOR SERIALIZED DOCUMENTS

| Sample Station | Sample Indentification Tag Number | Type of Analysis | Organic Traffic Report Number | Inorganic Traffic Report Number | High-Hazard Traffic Report Number | Dioxin Forms | Chain-of-Custody Record Number | Receipt-for-Samples Form Number | Airbill Number | Date Shipped |
|---|---|---|---|---|---|---|---|---|---|---|

## Exhibit 4-2
## DOCUMENT CONTROL PROCEDURES


PROJECT ACTIVITIES LOGBOOK (Daily Journal of Activities)
PROJECT NOTEBOOK (notes, correspondence, billings, etc.)
PLANS
Project Work Plan
Quality Assurance Work Plan
Site Health and Safety Plan
Draft and Final
Draft and Final
Draft and Final
FIELD SAMPLING MATERIALS
Field Notebook
Receipt-for-Samples Form
Copy (yellow)
Site Property Owner
Original (white)
Traffic Reports
Original (white)
Sample Management Office
1st Copy (pink)
Chain-of-Custody Record
Sample Identification Tag
Chain-of-Custody Seal
3rd Copy (yellow)
2nd Copy (white)
Original
Shipper/Laboratory
REPORTS
Analytical Reports
Study Reports, Field Data Reports, Drawings, etc.
Final
PROJECT INVENTORY NOTEBOOK (record of enforcement confidential and enforcement sensitive documents, authorized personnel, and serialized documents)
CLASSIFIED DOCUMENTS (enforcement confidential; enforcement sensitive)
ACTIVE PROJECT FILE
RDCO-Controlled File
RDCO-Controlled File
Return Immediately to EPA by Certified Mail
Prepare File Inventory
CLOSED PROJECT FILE FOR EPA
File Inventory
Project Plan
Project Activities Logbooks
Field Notebooks
Sample Identification Records
Analytical Reports
Project Notebooks
Reference Materials, Literature
On-Hand Sample Inventory
Project Inventory Logbook
Miscellaneous Maps, Drawings, Photos
Final Reports

NOTE: Special analytical service forms are distributed as follows:
Original (white) - SMO
1st Copy (yellow) - Active Project Files
2nd & 3rd Copies (pink & gold) - Shipper/Laboratory

The following information is recorded on the tag:

- **CLP Case / SAS Number(s):** The unique number(s) assigned by SMO to identify the sampling event (entered under "Remarks" heading)
- **CLP Sample Number:** The unique sample identification number (from the TR, DSR, or PL) used to document that sample (entered under "Remarks" heading)
- **Project Code:** An assigned contractor project number
- **Station Number:** A unique identifier assigned to a sampling point by the sampling team leader and listed in the sampling plan
- **Date:** A six-digit number indicating the year, month, and day of collection
- **Time:** A four-digit number indicating the local standard time of collection using the 24-hour clock notation (for example, 1345 for 1:45 p.m.)
- **Station Location:** The sampling station description as specified in the sampling plan
- **Samplers:** Each sampler's name and signature
- **Preservative:** Whether a preservative is used and the type of preservative
- **Analysis:** The type of analysis requested
- **Tag Number:** A unique serial number, stamped on each tag
- **Batch Number:** The sample container cleaning batch number, recorded in the "Remarks" section
- **Remarks:** The sampler's record of pertinent information, such as batch number, split samples, and special procedures
- **Laboratory Sample Number:** Reserved for laboratory use

The tag used for water, soil, sediment, and biotic samples contains an appropriate place for identifying the sample as a grab or a composite, the type of sample collected, and the preservative used, if any. The tag used for air samples requires the sampler to designate the sequence number and identify the sample type. Sample identification tags are attached to, or folded around each sample, and are taped in place.

After collection, separation, identification and preservation, a traffic report is completed and the sample is handled using chain-of-custody procedures discussed in the following sections. If the sample is to be split, aliquots are placed into similar sample containers. Depending on the EPA region, sample identification tags are completed and attached to each split and marked with the tag numbers of the other portions and with the word "split." Blank or duplicate samples are labeled in the same manner as "normal" samples. Information on blanks or duplicate samples is recorded in the field notebook. Some EPA regions require that laboratories be informed of the number of blanks and duplicates that are shipped, but not the identity of the quality assurance samples.

The printed and numbered adhesive sample labels affixed to the traffic reports are secured to sample containers by the sampler. Forms are filled out with waterproof ink, if weather permits. If a pen will not function because of inclement conditions, an indelible pencil may be used. If a pencil is used, a note ex-

## Exhibit 4-3
## TYPICAL RECEIPT-FOR-SAMPLES FORM

**United States**
**Environmental Protection Agency**
**Region 10**

### RECEIPT FOR SAMPLES

**Environmental Services Division**
**U.S. Environmental Protection Agency Region 10**
**1200 Sixth Avenue, Seattle, Washington 98101**

PROJECT NO.

PROJECT NAME

Name of Facility

SAMPLER(S): *(Signature)*

Facility Location

Split Samples Offered

( ) Accepted ( ) Declined

| Station Number | Date | Time | Corrs. | Grab | Split Samples | Tag Numbers | Station Description | No. of Containers | Remarks |
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Transferred by: *(Signature)*

Date

Time

Received by: *(Signature)*

Telephone Number

Title

Date

Time

Distribution: Original to Coordinator Field Files; Copy to Facility

№ 131

plaining the conditions must be included in the field notebook. When necessary, the label is protected from water and solvents with clear tape.

The original is sent to the SMO. The first copy is retained for the project file. The second and third copies are sent with the shipment to the laboratory. Complete instructions for the use of traffic reports are given in the *User's Guide to the CLP*.

### 4.6.2 Sample Traffic Report (TR)

The sample documentation system for the CLP sample preparation program is based on the use of the sample traffic report (TR), a four-part carbonless form printed with a unique sample identification number. One TR and its printed identification number is assigned by the sampler to each sample collected. The three types of TRs currently in use include organic, inorganic dioxin, and high-concentration TRs. (See Subsection 5.1.6 for examples of completed TRs.)

To provide a permanent record for each sample collected, the sampler completes the appropriate TR, recording the case number, site name or code and location, analysis laboratory, sampling office, dates of sample collection and shipment, and sample concentration and matrix. Numbers of sample containers and volumes are entered by the sampler, beside the analytical parameter(s) requested for particular sample portions.

### 4.6.3 Chain-of-Custody Forms and Records

Because samples collected during an investigation could be used as evidence in litigation, possession of the samples must be traceable from the time each is collected until it is introduced as evidence in legal proceedings. To document sample possession, chain-of-custody procedures are followed.

#### 4.6.3.1 Definition of Custody

A sample is under custody if one or more of the following criteria are met:

- The sample is in the sampler's possession.
- It is in the sampler's view after being in possession.
- It was in the sampler's possession and then was locked up to prevent tampering.
- It is in a designated secure area.

#### 4.6.3.2 Field Custody Procedures

Only enough of the sample should be collected to provide a good representation of the medium being sampled. To the extent possible, the quantity and types of samples and the sample locations are determined before the actual fieldwork. As few people as possible should handle the samples.

Field samplers are personally responsible for the care and custody of the samples collected by their teams until the samples are transferred or dispatched properly. A person is usually designated to receive the samples from the field samplers after decontamination; this person maintains custody until the samples are dispatched.

The SM determines whether proper custody procedures were followed during the fieldwork and decides if additional samples are required.

#### 4.6.3.3 Transfer of Custody and Shipment

Samples are accompanied by a chain-of-custody (COC) form or record (Exhibits 5-4 and 5-5). When transferring samples, the individuals relinquishing and receiving them should sign, date and note the time on the form. This form documents sample custody transfer from the sampler, often through another person, to the analyst, who is in a mobile or contract laboratory.

Samples are packaged properly for shipment and dispatched to the appropriate laboratory for analysis, with a separate COC record accompanying each shipment. Shipping containers are padlocked or sealed with custody seals for shipment to the laboratory. The method of shipment, courier name(s), and other pertinent information such as the laboratory name should be entered in the "Remarks" section of the COC record.

When samples are split with an owner, operator, or government agency, the event is noted in the "Remarks" section of the COC record. The note indicates with whom the samples are being split. The person relinquishing the samples to the facility or agency requests the signature of the receiving party on a receipt-for-samples form (Exhibit 4-3) (described in the following subsection), thereby acknowledging receipt of the samples. If a representative is unavailable or refuses to sign, this situation is noted in the "Remarks" section of the COC record. When appropriate, for example, when an owner's representative is unavailable, the COC record and receipt-for-samples form should contain a statement that the samples were delivered to the designated location at the designated time. A witness to the attempted delivery should be obtained. The samples shall be secured if no one is present to receive them.

All shipments are accompanied by a COC record identifying their contents. The original form accompanies the shipment; the copies are retained by the sampler and returned to the sampling coordinator.

If nonhazardous samples are sent by mail, the package is registered, and a return receipt is requested. Note: Hazardous materials shall not be sent by mail. If samples are sent by common carrier, a bill of lading is used. Air freight shipments are sent prepaid. Freight bills, postal service receipts, and bills of lading should be retained as part of the permanent documentation for the COC records.

#### 4.6.3.4 Laboratory Custody Procedures

Laboratory personnel are responsible for the care and custody of samples from the time they are received until the samples are exhausted or returned to the laboratory sample custodian for ultimate disposal. Laboratory-specific variations exist; however, a generally accepted laboratory chain-of-custody procedure is presented below. Any laboratory used for the analysis of samples taken in the course of EPA remedial response must have an adequate chain-of-custody procedure. This procedure is required as an exhibit in the Quality Assurance Project Plan (QAPjP) if the laboratory is not in the CLP.

A designated custodian of laboratory samples accepts custody of the shipped samples and verifies that the information on the sample identification tags matches that on the COC records. Pertinent information on shipment, pickup, courier, and condition of samples is entered in the "Remarks" section. The custodian then enters the sample identification tag data into a bound logbook, which is arranged by project code and station number.

The laboratory custodian uses the sample identification tag number or assigns a unique laboratory number to each sample; the custodian transfers the samples to the proper analyst or stores them in the appropriate secure area. A limited number of named individuals are allowed access to the sample storage area. The appropriate analysts are responsible for the samples until they are returned to the custodian.

When sample analyses and necessary quality assurance (QA) checks have been completed, the unused portion of the sample and the sample containers must be disposed of properly (see Subsection 5.2.6.4). All identifying tags, data sheets, and laboratory records, are retained as part of the permanent documentation.

### 4.6.4 Receipt-for-Samples Form

Section 3007(a)(2) of the RCRA states "If the officer, employee, or representative obtains any samples, prior to leaving the premises he shall give to the owner, operator, or agent-in-charge, a receipt describing the samples obtained and, if requested, a portion of each such sample equal in volume or weight to the portion retained." Section 104 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act (SARA), contains identical requirements.

Completing a receipt-for-samples form complies with these requirements; such forms should be used whenever splits are offered or provided to the site owner, operator, or agent-in-charge. The particular form used may vary between EPA regions; an example is shown in Exhibit 4-3. This form is completed and a copy given to the owner, operator, or agent-in-charge even if the offer for split samples is declined. The original is given to the SM and is retained in the project files. In addition, the contractor must provide analytical results from the samples collected to the owner, operator, or agent in charge, as mandated in SARA.

### 4.6.5 Custody Seals

When samples are shipped to the laboratory, they must be placed in padlocked containers or containers sealed with custody seals; a completed example is shown in Exhibit 5-6. Some custody seals are serially numbered. These numbers must appear in the cross-reference matrix (Exhibit 4-1) of the field document and on the COC report. Other types of custody seals include unnumbered seals and evidence tape.

When samples are shipped, two or more seals are to be placed on each shipping container (such as a cooler), with at least one at the front and one at the back, located in a manner that would indicate if the container were opened in transit. Wide, clear tape should be placed over the seals to ensure that seals are not accidentally broken during shipment. Nylon packing tape may be used providing that it does not completely cover the custody seal. Completely covering the seal with this type of tape may allow the label to be peeled off. Alternatively, evidence tape may be substituted for custody seals.

If samples are subject to interim storage before shipment, custody seals or evidence tape may be placed over the lid of the jar or across the opening of the storage box. Custody during shipping would be the same as described above. Evidence tape may also be used to seal the plastic bags or metal cans that are used to contain samples in the cooler or shipping container. Sealing individual sample containers assures that sample integrity will not be compromised if the outer container seals are accidentally broken.

### 4.6.6 Field Notebooks

A bound field notebook must be maintained by the sampling team leader to provide daily records of significant events, observations, and measurements during field investigations. All entries are to be signed and dated. All members of the field investigation team are to use this notebook, which is to be kept as a permanent record. Observations or measurements that are taken in an area where contamination of the field notebooks may occur may be recorded in a separate bound and numbered logbook before being transferred to the project notebook. The original records are retained, and the delayed entry is noted as such.

Field notebooks are intended to provide sufficient data and observations to enable participants to reconstruct events that occurred during projects and to refresh the memory of the field personnel if called upon to give testimony during legal proceedings. In a legal proceeding, notes, if referred to, are subject to cross-examination and are admissible as evidence. The field notebook entries should be factual, detailed, and objective.

### 4.6.7 Corrections to Documentation

Unless restricted by weather conditions, all original data recorded in field notebooks and on sample identification tags, chain-of-custody records, and receipt-for-samples forms are written in waterproof ink. These accountable serialized documents are not to be destroyed or thrown away, even if they are illegible or contain inaccuracies that require a replacement document.

If an error is made on an accountable document assigned to one person, that individual may make corrections simply by crossing out the error and entering the correct information. The erroneous information should not be obliterated. Any error discovered on an accountable document should be corrected by the person who made the entry. All corrections must be initialed and dated.

For all photographs taken, a photographic log is kept; the log records date, time, subject, frame and roll number, and photographer. For "instant photos," the date, time, subject, and photographer are recorded directly on the developed picture. The serial number of the camera and lens are recorded in the project notebook. The photographer should review the photographs or slides when they return from developing and compare them to the log, to assure that the log and photographs match. It can be particularly useful to photograph the labeled sample jars before packing them into shipping containers. A clear photograph of the sample jar, showing the label, any evidence tape sealing the jar, and the color and amount of sample, can be most useful in reconciling any later discrepancies.

## 4.7 REGION-SPECIFIC VARIANCES

Region-specific variances are common; the SM should contact the EPA RPM or the RSCC before any sampling campaign to ascertain the latest procedures. Future changes in variances will be incorporated in subsequent revisions to this compendium.

### 4.7.1 Region I

Region I uses a standard contractor serialized chain-of-custody form and an unnumbered chain-of-custody seal, which are placed on the outside of the shipping cooler. Numbered sample bottle labels are used for REM site work and numbered tags for FIT site work.

### 4.7.2 Region II

Region II uses an unnumbered chain-of-custody form and numbered sample bottle labels for all site work. Custody seals are placed on the outside of the shipping cooler.

### 4.7.3 Region III

Region III uses a serialized chain-of-custody form and numbered sampling tags. Chain-of-custody seals used by Region III are unnumbered and placed on the outside of the shipping cooler.

### 4.7.4 Region IV

Region IV has a detailed procedural discussion in the *Engineering Support Branch Standards Operating Procedures and Quality Assurance Manual*, U.S. EPA, Region IV, Environmental Services Division, 1 April 1986.

### 4.7.5 Region V

Region V uses a serialized chain-of-custody seal. Region V seals are color coded; orange is used for REM and FIT work. Seals are placed on the outside of the shipping cooler only if the samples are sent the same day as collected; otherwise, seals are placed across sample jar lids. FIT does not note whether or not samples were split on the chain-of-custody record. FIT includes the corresponding Traffic Report number under the remarks section of the tag. The bottle lot numbers or "batch numbers" are not recorded here, but on the "Chain-of Custody form."

### 4.7.6 Region VI

Region VI does not use a serialized number control system on custody seals.

### 4.7.7 Region VII

Region VII personnel provide onsite sample control. Samples are logged into a computer by regional personnel. Although contractor personnel do not seal and log samples, chain of custody is followed as described above.

### 4.7.8 Region VIII

Region VIII does not use a serialized number control system on custody seals.

### 4.7.9 Region IX

Region IX does not use a serialized number control system on chain-of-custody seals.

### 4.7.10 Region X

Region X does not use a serially numbered custody seal. Seals are signed, and the sample ID number is written on the seal.

## 4.8 INFORMATION SOURCES

*Superfund Amendments and Reauthorization Act (SARA)*. Section 104(m), "Information Gathering Access Authorities."

U.S. Environmental Protection Agency. *NEIC Policies and Procedures*. EPA-330/9-78-001-R. May 1978. (Revised February 1983.)

U.S. Environmental Protection Agency. *REM IV Zone Management Plan*. Contract No. 68-01-7251, CH2M HILL and U.S. EPA.

U.S. Environmental Protection Agency. *User's Guide to the Contract Laboratory Program*. Office of Emergency and Remedial Response. December 1986.

U.S. Environmental Protection Agency. *Zone II REM/FIT Quality Assurance Manual*. Contract No. 68-01-6692, CH2M HILL and Hazardous Site Control Division.

# SECTION 5

# LABORATORY INTERFACE

## 5.1 NATIONAL CONTRACT LABORATORY PROGRAM

**Note:** This section is organized by contract and noncontract laboratory programs to provide a clearer differentiation between programs.

### 5.1.1 Scope and Purpose

This subsection summarizes how to schedule analyses through the National Contract Laboratory Program (CLP), the types of services provided by the CLP, the paperwork involved in submitting samples to a CLP laboratory, and how to contact a CLP laboratory regarding final disposition of analytical data. A detailed discussion of the entire CLP, including the CLP tracking system, can be found in the *User's Guide to the CLP.*

### 5.1.2 Definitions and Abbreviations

**National Contract Laboratory Program (CLP)**
(See *User's Guide to the CLP.*)

**Regional Sample Control Center (RSCC)**
(See *User's Guide to the CLP.*)

**Sample Management Office (SMO)**
(See *User's Guide to the CLP.*)

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

### 5.1.3 Applicability

This subsection is applicable to samples collected during Superfund projects. Only EPA may grant exceptions to the required use of CLP. The use of CLP is a requirement only when justified by the choice of data quality objectives (DQO). There will be many opportunities to use mobile laboratories, screening protocols, subcontracted private laboratories or EPA regional laboratories.

### 5.1.4 Responsibilities

Detailed responsibilities are described in Subsection 5.1.6 on procedures. General responsibilities are given to the following:

- Site Managers for planning the sampling dates and analytical requirements
- EPA Remedial Project Managers (RPMs) for communicating the sampling or analytical schedule to the RSCC
- RSCC for deciding sample priorities within their region and for telling SMO their analytical needs on a monthly, as well as a weekly, basis
- SMO for scheduling sample analysis, communicating the laboratory information back to the RSCC, and contacting the laboratories concerning late or missing data
- Sampling personnel for completing the required paperwork and for contacting SMO and RSCC with shipping information

## 5.1.5 Records

The following sample documentation is required (examples are given in Subsection 5.1.6):

- Organic traffic report
- Inorganic traffic report
- High-concentration traffic report
- CLP dioxin shipment record
- Special analytical service packing list
- Sample tag and label
- Custody seal
- Chain-of-custody (COC) form

**Note:** All of the above are not required for each sample collected. The reader should refer to subsection 5.1.6 for specific requirements.

## 5.1.6 Procedures

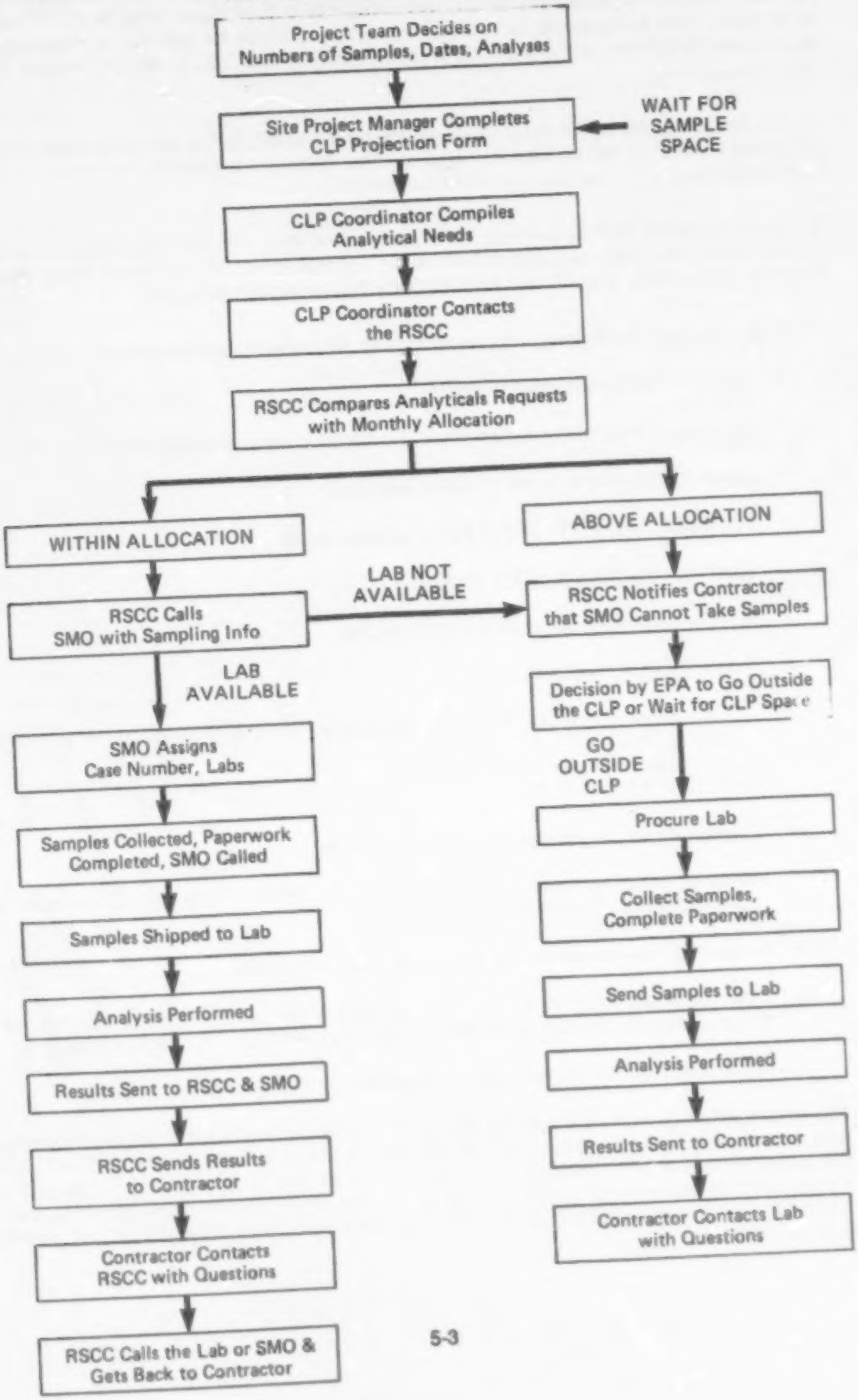
The procedures in this subsection are presented in the chronological order used during a routine sampling episode; they are applicable to routine, as well as special, analytical services. Exhibit 5-1 summarizes the process from start to finish. These procedures are generic with an approach to regional differences discussed in Subsection 5.1.7. (See also Subsection 6.1.6.1.)

### 5.1.6.1 Activities Before Sampling

1. The project team decides what sampling is to occur at the site and the analyses to be performed, based on available data. The CLP provides a choice of two analytical services: routine and special. Routine analytical services include analysis of a soil or water sample at low-to-

**Exhibit 5-1**

**ROUTINE SAMPLING PROCESS**


Project Team Decides on Numbers of Samples, Dates, Analyses
Site Project Manager Completes CLP Projection Form
WAIT FOR SAMPLE SPACE
CLP Coordinator Compiles Analytical Needs
CLP Coordinator Contacts the RSCC
RSCC Compares Analyticals Requests with Monthly Allocation
WITHIN ALLOCATION
ABOVE ALLOCATION
RSCC Calls SMO with Sampling Info
LAB NOT AVAILABLE
RSCC Notifies Contractor that SMO Cannot Take Samples
LAB AVAILABLE
Decision by EPA to Go Outside the CLP or Wait for CLP Space
SMO Assigns Case Number, Labs
GO OUTSIDE CLP
Procure Lab
Samples Collected, Paperwork Completed, SMO Called
Collect Samples, Complete Paperwork
Samples Shipped to Lab
Send Samples to Lab
Analysis Performed
Analysis Performed
Results Sent to RSCC & SMO
Results Sent to Contractor
RSCC Sends Results to Contractor
Contractor Contacts Lab with Questions
Contractor Contacts RSCC with Questions
RSCC Calls the Lab or SMO & Gets Back to Contractor

medium concentration levels (<15 per cent of any single compound) for the Target Compound List (TCL) organics and/or inorganics with a 30-day to 45-day turnaround requirement. The TCL includes organic compounds, trace elements and cyanide. Special analytical services include any analysis that is not routine, such as analysis for non-TCL compounds; different turnaround times; high concentration soils, water, drums, etc.; or different sample media (e.g., fish, air, etc.).

2. The SM completes a CLP monthly projection form that details the sampling anticipated for the present month as well as the following 2 months. This form is submitted to the contractor's CLP coordinator, who compiles the analytical needs.

3. The contractor's CLP coordinator contacts the EPA RPM with the information. The RPM contacts the authorized requesters (AR) at the appropriate RSCC and gives them the appropriate information. The AR calls the SMO with the necessary information.

The SMO requires the following information from an AR to initiate a RAS request:

- Name of RSCC authorized requester
- Name(s), association, and telephone number(s) of sampling personnel
- Name, city, and state of the site to be sampled
- Superfund site / spill ID (2-digit alpha-numeric code)
- Dioxin tier assignment, where applicable
- Number and matrix of samples to be collected
- Type of analyses required
  - Organics: Full (VOA, BNA, and pesticides / PCB) or VOA and/or BNA and/or pesticides / PCB
  - Inorganic: Metals and/or cyanide
  - Dioxin: 2,3,7,8-TCDD
- Scheduled sample collection and shipment dates
- Nature of sampling event (i.e., investigation, monitoring, enforcement, remedial, drilling project, CERCLA Cooperative Agreements)
- Suspected hazards associated with the sample and/or site
- Other pertinent information that may affect sample scheduling or shipment (i.e., anticipated delays because of site access, weather conditions, sampling equipment)
- Name(s) of regional or contractor contacts for immediate problem resolution

This information is submitted to the RSCC as early as possible before the anticipated sampling date. A minimum of 2 weeks lead time is strongly suggested for RAS requests. Changes in the sample schedule are relayed to the RSCC as soon as they become known. It should be recognized that changes in the sampling schedule may delay laboratory assignments, especially if they are frequent or "last minute." This reporting sometimes necessitates daily contact with the RSCC.

RSCC telephone numbers are found in the *User's Guide to the CLP*, Appendix A.

4. Special Analytical Service (SAS) is handled slightly differently. Because these services are individually procured on a competitive basis, a minimum lead time of 2 weeks is required to process a completely defined SAS request. More lead time is strongly recommended whenever possible. Certain types of SAS requests require a longer lead time, as follows: A minimum lead time of 2 to 3 weeks is required for SAS requests that involve distribution of protocols. A minimum lead time of 4 or more weeks is recommended for large-scale, analytically complex, and/or non-Superfund SAS requests. Award of non-Superfund SAS subcontracts may be made only after the appropriate funding process is complete.

SMO requires the following information from an AR to initiate an SAS request:

- Name of RSCC authorized requestor
- Name(s), association, and telephone number(s) of sampling personnel
- Name, city and state of the site to be sampled
- Superfund site / spill ID (2-digit alpha-numeric code)
- Number and matrix of samples to be collected
- Specific analyses required and appropriate protocols and QA/QC
- Required detection limits
- Matrix spike and duplicate frequency
- Data turnaround and data format
- Justification for fast turnaround request, if appropriate
- Scheduled sample collection and shipment dates
- Nature of sampling event (i.e., investigation, monitoring, enforcement, remedial, drilling project, CERCLA Cooperative Agreements)
- Suspected hazards associated with the samples and/or site
- Other pertinent information that may affect sample scheduling or shipment (i.e., anticipated delays because of site access, weather condition, sampling equipment)
- Name(s) of regional or contractor contacts for immediate problem resolution

5. The RSCC contacts SMO to schedule analysis at least 1 week before start of sampling for Routine Analytical Analysis (RAS) only; for SAS, additional time is needed. SMO assigns a case number, an SAS number (if applicable) and laboratories; this information is communicated to the RSCC.

6. The RSCC contacts the RPM or the SM regarding the case number, SAS number, and laboratory information no later than noon on the Wednesday of the week before sample shipment. The RSCC also provides traffic reports, custody seals, SAS packing lists, chain-of-custody forms, sample tags, and CLP dioxin shipment record forms, as appropriate for EPA/CLP sampling events.

#### 5.1.6.2. Sampling Activities

1. During the sampling process, sampling personnel maintain close contact with SMO and RSCC, relaying sampling information, shipping information, problems encountered during sampling, and any changes from the originally scheduled sampling program. Shipping information is called in to SMO before 5:00 p.m. Eastern Standard Time (EST) on the day of shipment or by 8:00 a.m. EST the next day. Friday-shipments are called in to SMO before 3:00 p.m. EST to confirm Saturday delivery.

2. Samplers should provide SMO with the following information during the call:

- Sampler name and phone number
- Case number and/or SAS number of the project
- Site name / code
- Batch numbers (dioxin only)
- Exact number(s), matrixes and concentration(s) of samples shipped
- Laboratory(ies) that samples were shipped to
- Carrier name and airbill number(s) for the shipment
- Method of shipment (e.g., overnight, 2-day)
- Date of shipment
- Suspected hazards associated with the samples or site
- Any irregularities or anticipated problems with the samples, including special handling instructions, or deviations from established sampling procedures
- Status of the sampling project (e.g., final shipment, update of future shipping schedule)

3. Samplers must complete the required SMO / CLP paperwork before sample shipment. Examples of properly completed forms are given in Exhibits 5-2 through 5-10. (Also see Section 4 for information regarding sample control and chain-of-custody reports.)

4. The designated copies of the completed paperwork are sent to the laboratory or SMO, as appropriate. All paperwork must be submitted within the same week of the sampling event.

## Exhibit 5-2
## TYPICAL ORGANICS TRAFFIC FORM

U.S. ENVIRONMENTAL PROTECTION AGENCY HWI Sample Management Office

# ORGANICS TRAFFIC REPORT

Sample Number
AH 719

① **Case Number:** 9999

**Sample Site Name/Code:** CHEMICAL SOUP/ $750.75

② **SAMPLE CONCENTRATION**
(Check One)

X Low Concentration
___ Medium Concentration

③ **SAMPLE MATRIX**
(Check One)

X Water
___ Soil/Sediment

④ **Ship To:**
QZR LAB
321 ROAD STREET
SOMETOWN, STATE 12345

Attn: SAMPLER COORDINATOR

Transfer
Ship To:

⑤ **Regional Office:** [illegible]

Sampling Personnel:
SAMPLER
(Name)
412/788-1080
(Phone)

**Sampling Date:**
1/15/85
(Begin) (End)

⑥ **For each sample collected specify numbe of containers used and mark volume level on each bottle.**

| | Number of Containers | Approxima Total Volur |
|---|---|---|
| Water (Extractable) | 2 | 1 gal |
| Water (VOA) | 2 | 80 ml |
| Soil/Sediment (Extractable) | | |
| Soil/Sediment (VOA) | | |
| Other | | |
| | | |
| | | |
| | | |

AH 719 - Water (Extractable)
AH 719 - Water (Extractable)
AH 719 - Water (Extractable)
AH 719 - Water (Extractable)
AH 719 - Water (VOA)
AH 719 - Water (VOA)
AH 719 - Soil/Sediment (Extractable)
AH 719 - Soil/Sediment (Extractable)
AH 719 - Soil/Sediment (VOA)
AH 719 - Soil/Sediment (VOA)

⑦ **Shipping Information**

FEDERAL EXPRESS
Name of Carrier

1/15/85
Date Shipped:

350262356
Airbill Number:

⑧ **Sample Description**

___ Surface Water
___ Ground Water
___ Leachate
___ Mixed Media
___ Solids
___ Other (specify) ______

⑨ **Sampl**

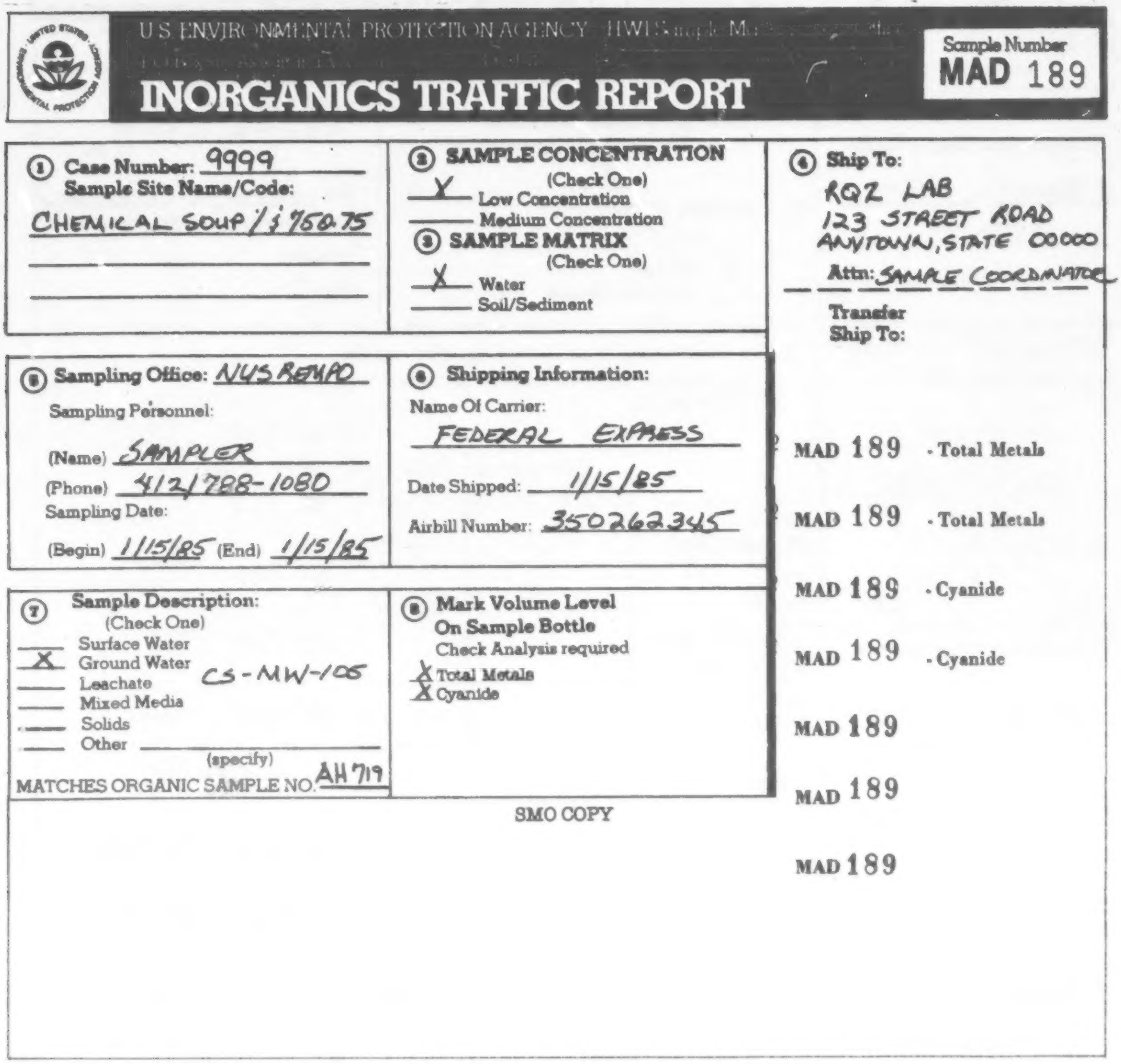
CS-MW-105

MATCHES ITR # MAD 189

⑩ **Special Handling Instructions:**
(e.g., safety precautions, hazardous nature)

SMO COPY

## Exhibit 5-3
## TYPICAL INORGANICS TRAFFIC FORM



U.S. ENVIRONMENTAL PROTECTION AGENCY HWI Sample M [illegible]

[illegible]

**INORGANICS TRAFFIC REPORT**

Sample Number
**MAD 189**

① **Case Number:** 9999
**Sample Site Name/Code:**
CHEMICAL SOUP / $ 750.75

② **SAMPLE CONCENTRATION**
(Check One)
X Low Concentration
___ Medium Concentration

③ **SAMPLE MATRIX**
(Check One)
X Water
___ Soil/Sediment

④ **Ship To:**
RQZ LAB
123 STREET ROAD
ANYTOWN, STATE 00000
**Attn:** SAMPLE COORDINATOR

**Transfer Ship To:**

⑤ **Sampling Office:** NUS REMPO
Sampling Personnel:
(Name) SAMPLER
(Phone) 412/788-1080
Sampling Date:
(Begin) 1/15/85 (End) 1/15/85

⑥ **Shipping Information:**
Name Of Carrier:
FEDERAL EXPRESS
Date Shipped: 1/15/85
Airbill Number: 350262345

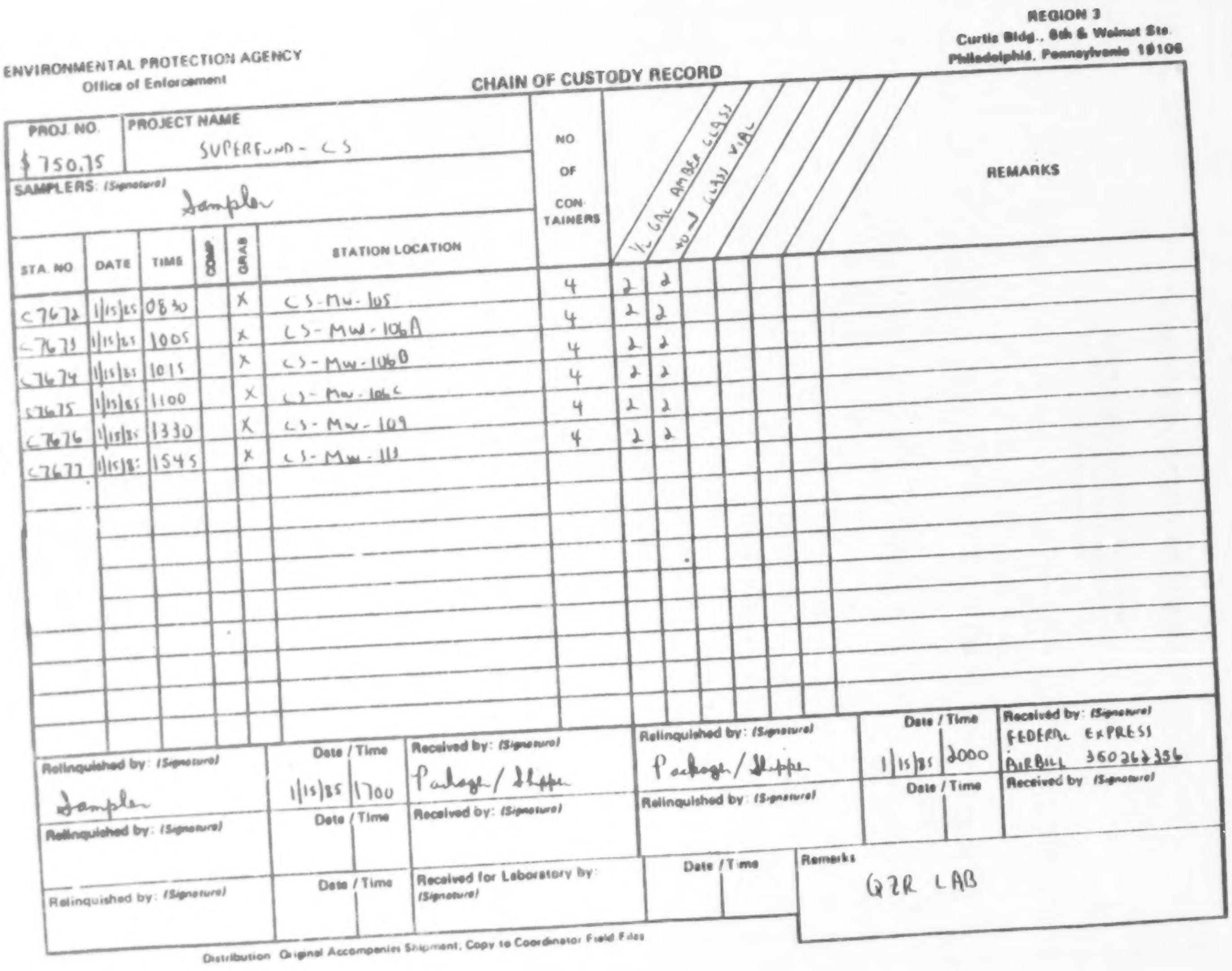
⑦ **Sample Description:**
(Check One)
___ Surface Water
X Ground Water
___ Leachate
___ Mixed Media
___ Solids
___ Other ________ (specify)
CS-MW-105
MATCHES ORGANIC SAMPLE NO. AH 719

⑧ **Mark Volume Level On Sample Bottle**
Check Analysis required
X Total Metals
X Cyanide

MAD 189 - Total Metals
MAD 189 - Total Metals
MAD 189 - Cyanide
MAD 189 - Cyanide
MAD 189
MAD 189
MAD 189

SMO COPY

# Exhibit 5-4
# TYPICAL CHAIN-OF-CUSTODY FORM
# (REGION III EXAMPLE)



ENVIRONMENTAL PROTECTION AGENCY
Office of Enforcement

REGION 3
Curtis Bldg., 6th & Walnut Sts.
Philadelphia, Pennsylvania 19106

**CHAIN OF CUSTODY RECORD**

PROJ. NO. $750.75

PROJECT NAME SUPERFUND - CS

SAMPLERS: *(Signature)* Sampler

| STA. NO | DATE | TIME | COMP | GRAB | STATION LOCATION | NO. OF CONTAINERS | ½ GAL AMBER GLASS | 40 ml GLASS VIAL | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C7672 | 1/15/85 | 0830 | | X | CS-MW-105 | 4 | 2 | 2 | | | | | |
| C7673 | 1/15/85 | 1005 | | X | CS-MW-106A | 4 | 2 | 2 | | | | | |
| C7674 | 1/15/85 | 1015 | | X | CS-MW-106B | 4 | 2 | 2 | | | | | |
| C7675 | 1/15/85 | 1100 | | X | CS-MW-106C | 4 | 2 | 2 | | | | | |
| C7676 | 1/15/85 | 1330 | | X | CS-MW-109 | 4 | 2 | 2 | | | | | |
| C7677 | 1/15/85 | 1545 | | X | CS-MW-113 | | | | | | | | |

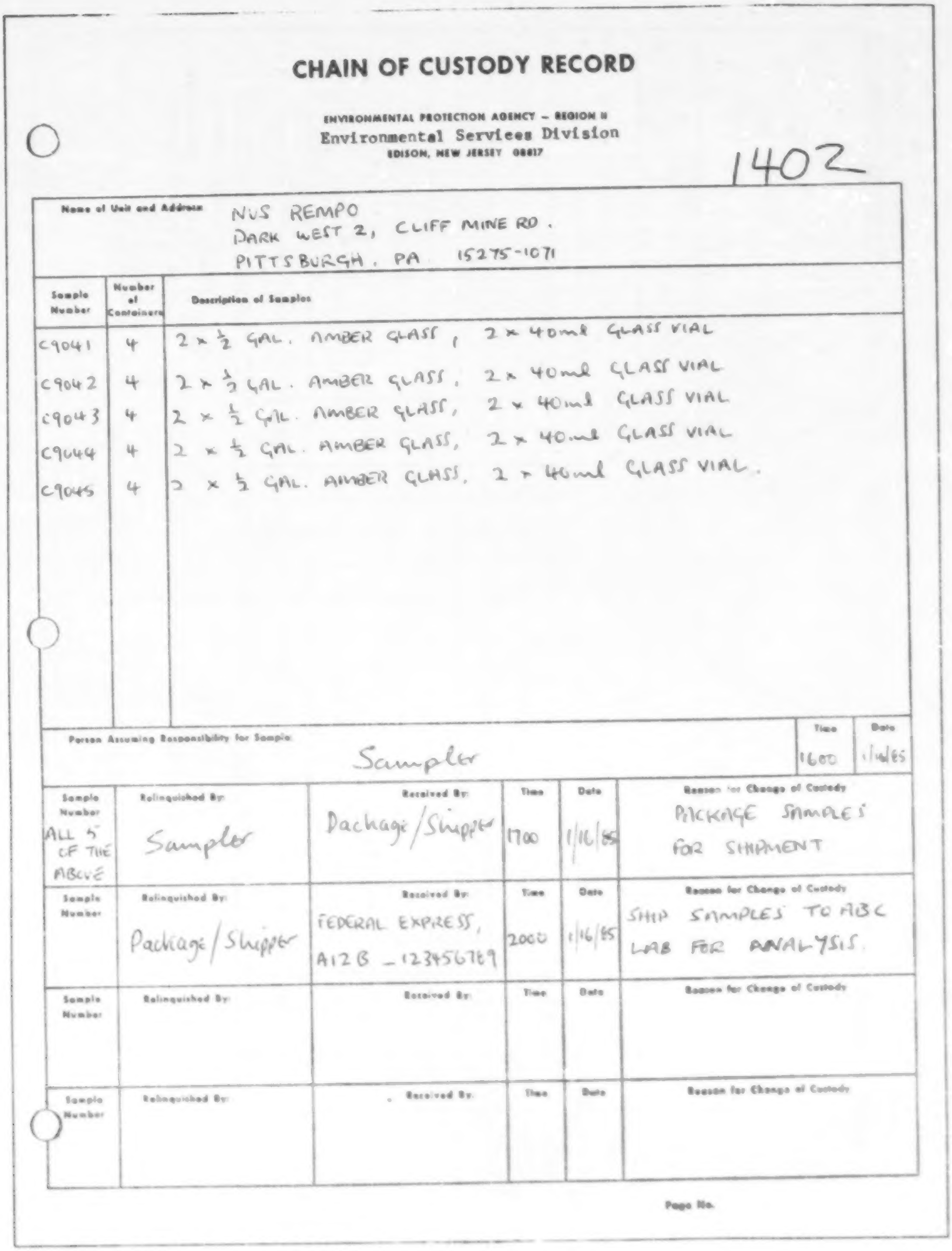
Relinquished by: *(Signature)* Sampler
Date / Time 1/15/85 1700
Received by: *(Signature)* Package/Shipper
Relinquished by: *(Signature)* Package/Shipper
Date / Time 1/15/85 2000
Received by: *(Signature)* FEDERAL EXPRESS AIRBILL 360267356

Relinquished by: *(Signature)*
Date / Time
Received by: *(Signature)*
Relinquished by: *(Signature)*
Date / Time
Received by: *(Signature)*

Relinquished by: *(Signature)*
Date / Time
Received for Laboratory by: *(Signature)*
Date / Time
Remarks QZR LAB

Distribution: Original Accompanies Shipment; Copy to Coordinator Field Files

## Exhibit 5-5
## CHAIN-OF-CUSTODY RECORD USED BY REGION II IN LIEU OF CHAIN-OF-CUSTODY FORM



### CHAIN OF CUSTODY RECORD

ENVIRONMENTAL PROTECTION AGENCY – REGION II
Environmental Services Division
EDISON, NEW JERSEY 08817

1402

Name of Unit and Address:
NUS REMPO
PARK WEST 2, CLIFF MINE RD.
PITTSBURGH, PA 15275-1071

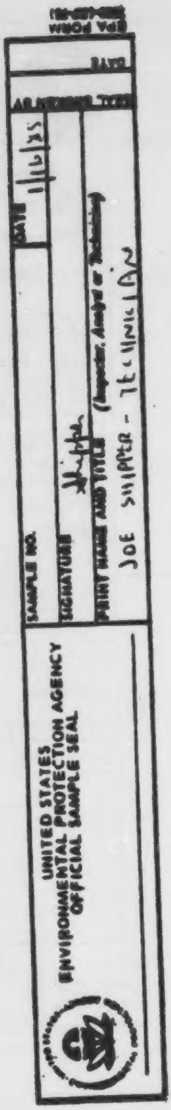
| Sample Number | Number of Containers | Description of Samples |
|---|---|---|
| C9041 | 4 | $2 \times \frac{1}{2}$ GAL. AMBER GLASS, $2 \times 40$ml GLASS VIAL |
| C9042 | 4 | $2 \times \frac{1}{2}$ GAL. AMBER GLASS, $2 \times 40$ml GLASS VIAL |
| C9043 | 4 | $2 \times \frac{1}{2}$ GAL. AMBER GLASS, $2 \times 40$ml GLASS VIAL |
| C9044 | 4 | $2 \times \frac{1}{2}$ GAL. AMBER GLASS, $2 \times 40$ml GLASS VIAL |
| C9045 | 4 | $2 \times \frac{1}{2}$ GAL. AMBER GLASS, $2 \times 40$ml GLASS VIAL. |

| Person Assuming Responsibility for Sample: | Time | Date |
|---|---|---|
| Sampler | 1600 | 1/16/85 |

| Sample Number | Relinquished By: | Received By: | Time | Date | Reason for Change of Custody |
|---|---|---|---|---|---|
| ALL 5 OF THE ABOVE | Sampler | Package/Shipper | 1700 | 1/16/85 | PACKAGE SAMPLES FOR SHIPMENT |
| | Package/Shipper | FEDERAL EXPRESS,<br>A12B _ 123456789 | 2000 | 1/16/85 | SHIP SAMPLES TO ABC LAB FOR ANALYSIS. |
| | | | | | |
| | | | | | |

Page No.

# Exhibit 5-6
## TYPICAL CUSTODY SEALS



UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
OFFICIAL SAMPLE SEAL

SAMPLE NO.

DATE 1/16/85

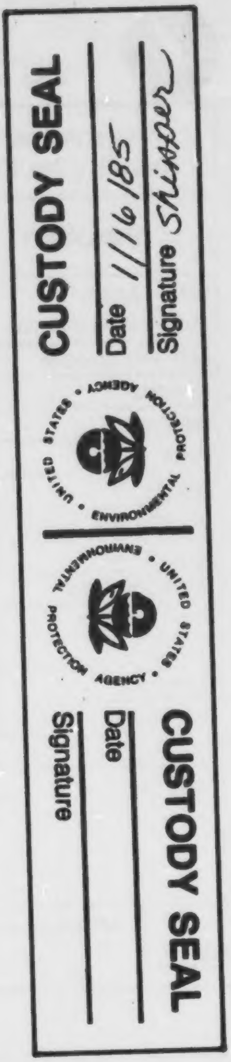
SIGNATURE

PRINT NAME AND TITLE (Inspector, Analyst or Technician)
JOE SHIPPER - TECHNICIAN

[illegible]

DATE

EPA FORM [illegible]



CUSTODY SEAL

Date 1/16/85

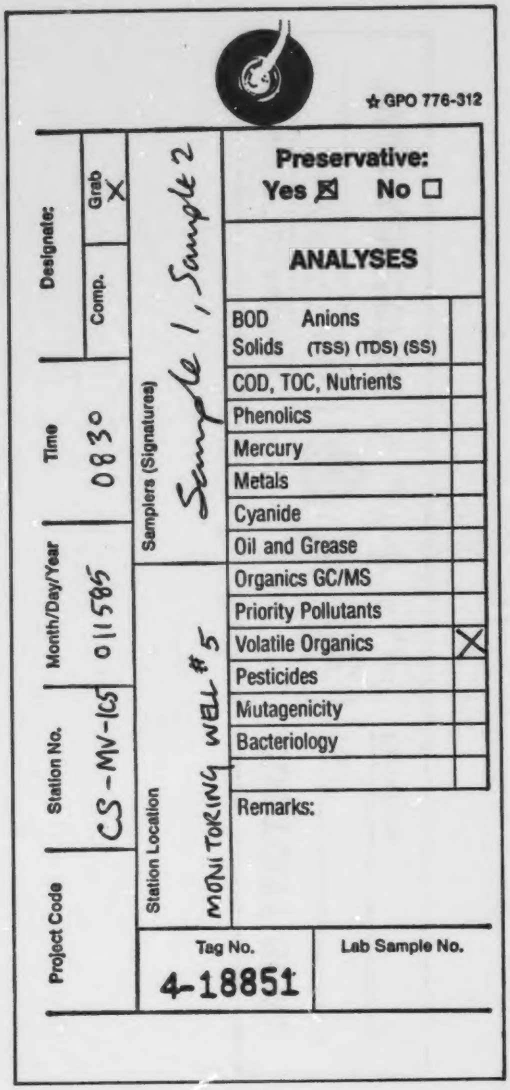
Signature Shipper

CUSTODY SEAL

Date

Signature

## Exhibit 5-7
## TYPICAL SAMPLE IDENTIFICATION TAGS



☆ GPO 776-312

Designate: Comp. Grab X
Time: 0830
Month/Day/Year: 011585
Station No.: CS-MV-1C5
Project Code:
Samplers (Signatures): Sample 1, Sample 2
Station Location: MONITORING WELL #5

**Preservative:**
Yes ☒ No ☐

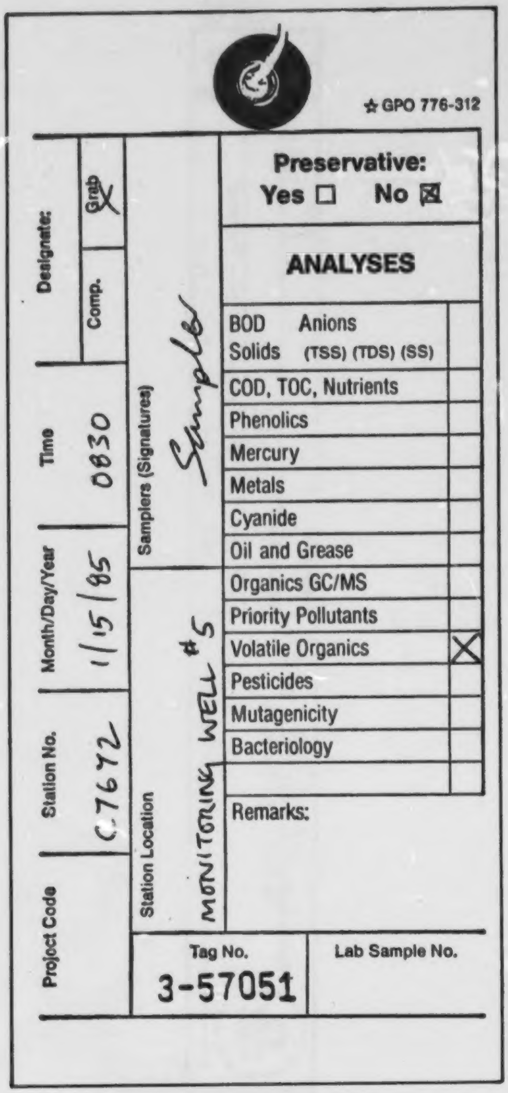
**ANALYSES**

| | |
|---|---|
| BOD Anions<br>Solids (TSS) (TDS) (SS) | |
| COD, TOC, Nutrients | |
| Phenolics | |
| Mercury | |
| Metals | |
| Cyanide | |
| Oil and Grease | |
| Organics GC/MS | |
| Priority Pollutants | |
| Volatile Organics | ☒ |
| Pesticides | |
| Mutagenicity | |
| Bacteriology | |
| | |

Remarks:

Tag No. 4-18851
Lab Sample No.

Region IV Sample Tag



☆ GPO 776-312

Designate: Comp. Grab X
Time: 0830
Month/Day/Year: 1/15/85
Station No.: C7672
Project Code:
Samplers (Signatures): Sampler
Station Location: MONITORING WELL #5

**Preservative:**
Yes ☐ No ☒

**ANALYSES**

| | |
|---|---|
| BOD Anions<br>Solids (TSS) (TDS) (SS) | |
| COD, TOC, Nutrients | |
| Phenolics | |
| Mercury | |
| Metals | |
| Cyanide | |
| Oil and Grease | |
| Organics GC/MS | |
| Priority Pollutants | |
| Volatile Organics | ☒ |
| Pesticides | |
| Mutagenicity | |
| Bacteriology | |
| | |

Remarks:

Tag No. 3-57051
Lab Sample No.

Region III Sample Tag

Note: The obverse side of the sample tag bears an EPA logo and the appropriate regional address.

## Exhibit 5-8
## SPECIAL ANALYTICAL SERVICES
## PACKING LIST

**U.S. ENVIRONMENTAL PROTECTION AGENCY**
CLP Sample Management Office
P.O. Box 818 - Alexandria, Virginia 22313
Phone: 703/557-2490 - FTS/557-2490

**SAS Number** 999C

**SPECIAL ANALYTICAL SERVICE**

PACKING LIST

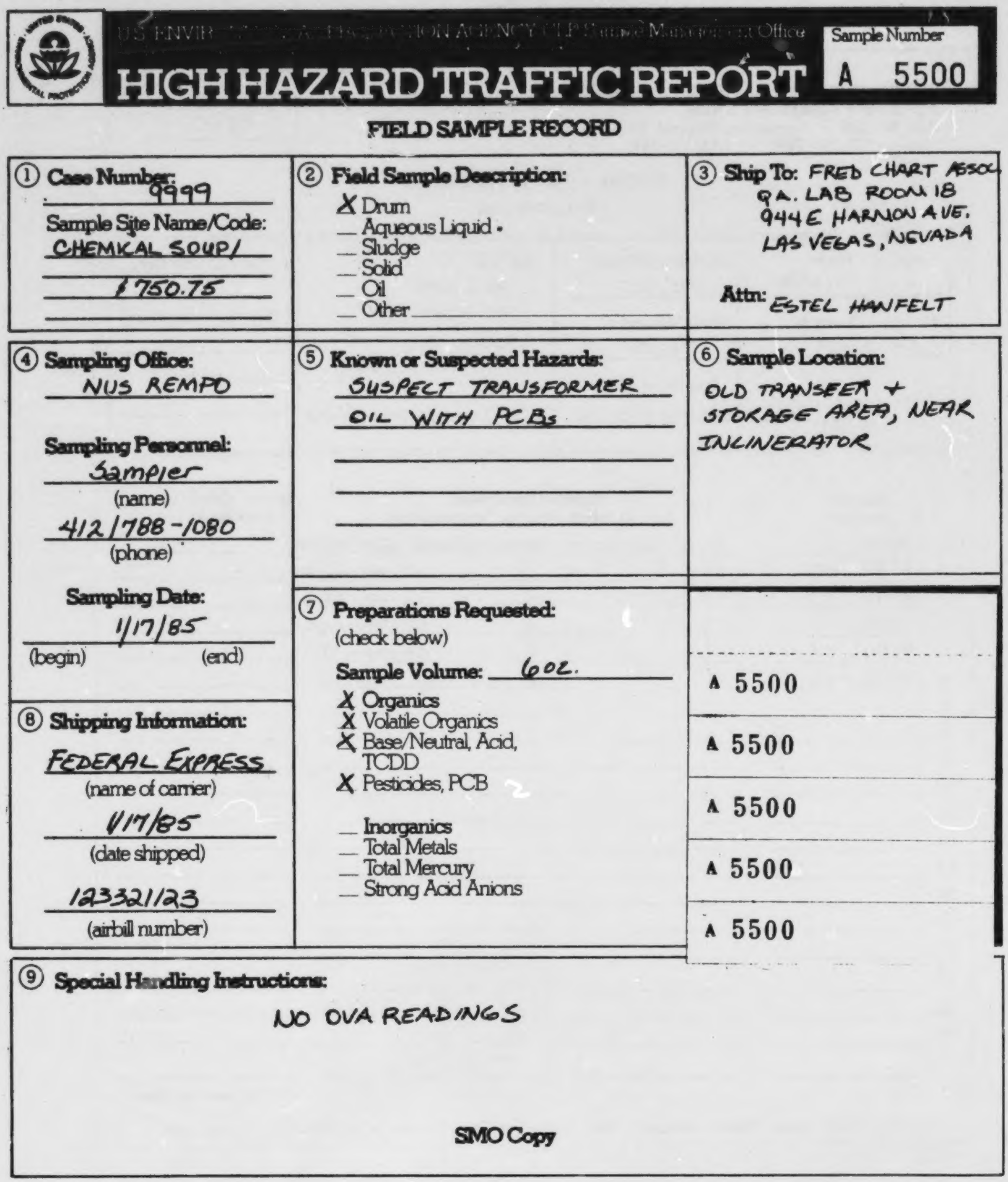
| | | | |
|---|---|---|---|
| **Sampling Office:** NUS REMPO<br>**Sampling Contact:** SAMPLER (name)<br>412/788-1080 (phone) | **Sampling Date(s):** 1/15/85<br>**Date Shipped:** 1/15/85<br>**Site Name/Code:** SUPERFUND CS/B750 | **Ship To:**<br>ABM LAB<br>107 ROAD AVE<br>YORKTOWN, STATE<br>12345<br>**Attn:** SAMPLE COORDINATOR | **For Lab Use Only**<br>**Date Samples Rec'd:**<br>**Received By:** |

| | Sample Numbers | Sample Description i.e., Analysis, Matrix, Concentration | Sample Condition on Receipt at Lab |
|---|---|---|---|
| 1. | 999C-01 | TDX LOW CONCENTRATION WATER CS-MW-105 | |
| 2. | 999C-02 | TDX CS-MW-106A | |
| 3. | 999C-03 | CS-MW-106B | |
| 4. | 999C-04 | CS-MW-106C | |
| 5. | 999C-05 | CS-MW-109 | |
| 6. | 999C-06 | CS-MW-113 | |
| 7. | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| 13. | | | |
| 14. | | | |
| 15. | | | |
| 16. | | | |
| 17. | | | |
| 18. | | | |
| 19. | | | |
| 20. | | | |

**For Lab Use Only**

White - SMO Copy, Yellow - Region Copy, Pink - Lab Copy for return to SMO, Gold - Lab Copy

**Exhibit 5-9**
**HIGH-HAZARD TRAFFIC REPORT**



U.S. ENVIRONMENTAL PROTECTION AGENCY CLP Sample Management Office

# HIGH HAZARD TRAFFIC REPORT

Sample Number
A 5500

## FIELD SAMPLE RECORD

① **Case Number:** 9999
**Sample Site Name/Code:** CHEMKAL SOUP/
$750.75

② **Field Sample Description:**
☒ Drum
☐ Aqueous Liquid
☐ Sludge
☐ Solid
☐ Oil
☐ Other

③ **Ship To:** FRED CHART ASSOC
QA. LAB ROOM 18
944 E HARMON AVE.
LAS VEGAS, NEVADA
**Attn:** ESTEL HANFELT

④ **Sampling Office:** NUS REMPO
**Sampling Personnel:** Sampler
(name)
412/788-1080
(phone)
**Sampling Date:** 1/17/85
(begin) (end)

⑤ **Known or Suspected Hazards:** SUSPECT TRANSFORMER OIL WITH PCBs

⑥ **Sample Location:** OLD TRANSFER + STORAGE AREA, NEAR INCINERATOR

⑦ **Preparations Requested:**
(check below)
**Sample Volume:** 6 oz.
☒ Organics
☒ Volatile Organics
☒ Base/Neutral, Acid, TCDD
☒ Pesticides, PCB
☐ Inorganics
☐ Total Metals
☐ Total Mercury
☐ Strong Acid Anions

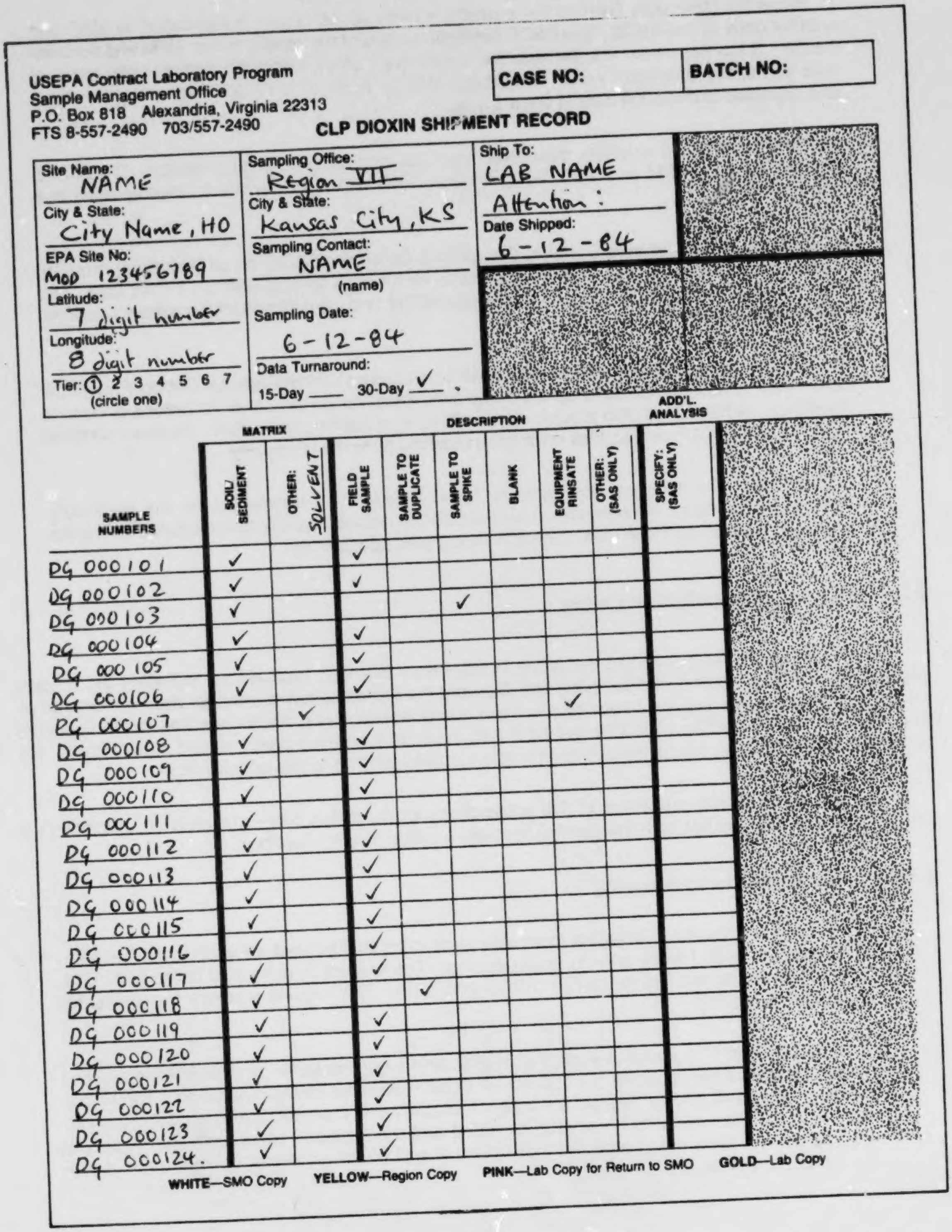
A 5500
A 5500
A 5500
A 5500
A 5500

⑧ **Shipping Information:** FEDERAL EXPRESS
(name of carrier)
1/17/85
(date shipped)
123321123
(airbill number)

⑨ **Special Handling Instructions:**
NO OVA READINGS

SMO Copy

## Exhibit 5-10
## CLP DIOXIN SHIPMENT RECORD



USEPA Contract Laboratory Program
Sample Management Office
P.O. Box 818 Alexandria, Virginia 22313
FTS 8-557-2490 703/557-2490

CASE NO:
BATCH NO:

**CLP DIOXIN SHIPMENT RECORD**

Site Name: NAME
City & State: City Name, MO
EPA Site No: MOD 123456789
Latitude: 7 digit number
Longitude: 8 digit number
Tier: [✓ 1] 2 3 4 5 6 7 (circle one)

Sampling Office: Region VII
City & State: Kansas City, KS
Sampling Contact: NAME (name)
Sampling Date: 6-12-84
Data Turnaround: 15-Day ____ 30-Day ✓

Ship To: LAB NAME
Attention:
Date Shipped: 6-12-84

| SAMPLE NUMBERS | MATRIX: SOIL/SEDIMENT | MATRIX: OTHER: SOLVENT | DESCRIPTION: FIELD SAMPLE | DESCRIPTION: SAMPLE TO DUPLICATE | DESCRIPTION: SAMPLE TO SPIKE | DESCRIPTION: BLANK | DESCRIPTION: EQUIPMENT RINSATE | DESCRIPTION: OTHER: (SAS ONLY) | ADD'L. ANALYSIS: SPECIFY: (SAS ONLY) |
|---|---|---|---|---|---|---|---|---|---|
| DG 000101 | ✓ | | ✓ | | | | | | |
| DG 000102 | ✓ | | ✓ | | | | | | |
| DG 000103 | ✓ | | | | ✓ | | | | |
| DG 000104 | ✓ | | ✓ | | | | | | |
| DG 000105 | ✓ | | ✓ | | | | | | |
| DG 000106 | ✓ | | ✓ | | | | ✓ | | |
| DG 000107 | | ✓ | | | | | | | |
| DG 000108 | ✓ | | ✓ | | | | | | |
| DG 000109 | ✓ | | ✓ | | | | | | |
| DG 000110 | ✓ | | ✓ | | | | | | |
| DG 000111 | ✓ | | ✓ | | | | | | |
| DG 000112 | ✓ | | ✓ | | | | | | |
| DG 000113 | ✓ | | ✓ | | | | | | |
| DG 000114 | ✓ | | ✓ | | | | | | |
| DG 000115 | ✓ | | ✓ | | | | | | |
| DG 000116 | ✓ | | ✓ | | | | | | |
| DG 000117 | ✓ | | ✓ | | | | | | |
| DG 000118 | ✓ | | | ✓ | | | | | |
| DG 000119 | ✓ | | ✓ | | | | | | |
| DG 000120 | ✓ | | ✓ | | | | | | |
| DG 000121 | ✓ | | ✓ | | | | | | |
| DG 000122 | ✓ | | ✓ | | | | | | |
| DG 000123 | ✓ | | ✓ | | | | | | |
| DG 000124. | ✓ | | ✓ | | | | | | |

**WHITE**—SMO Copy **YELLOW**—Region Copy **PINK**—Lab Copy for Return to SMO **GOLD**—Lab Copy

### 5.1.6.3 Postsampling Activities

1. When the laboratory finishes the analysis, a copy of the results is forwarded to SMO and another copy to the RSCC. The RSCC forwards a copy of the results to the RPM and the contractor. If the results do not arrive at the contractor's office within the contractually required time frame, the contractor's CLP coordinator initiates a call to the RSCC regarding the status and expected completion data of the analysis.

2. Once the data are received, questions may arise regarding their interpretation. The SM will contact the EPA RPM or RSCC, who contacts SMO or the laboratory to resolve questions about the data.

3. SMO routinely performs Contract Compliance Screening (CCS) on all RAS data; modified CCS can be performed on a case-by-case basis for mixed RAS-plus-SAS or all -SAS data. This review determines completeness of data deliverables and compliance with contract specification by the laboratory.

4. Data review services are provided by SMO upon request of the Regional Deputy Project Officer. Data review can be used by the SM to determine the usability and limitations of data, to maximize usable data and to provide standardized data quality assessment. Review cannot be initiated until all CLP deliverables have been received from the laboratory.

Contractually, the required time span is for analyses to be conducted by the laboratory. Review and validation for compliance with quality assurance / quality control (QA/QC) requirements consume additional time. The SM should plan accordingly.

## 5.1.7 Region-Specific Variances

Each EPA region has developed variations in laboratory interface procedures, including the records procedures for sampling and postsampling activities and the individual forms used for the individual tasks. Information on variations provided here may become dated rapidly. Thus, it is imperative that the user contact the individual EPA RPM or RSCC to get full details on current regional practices and requirements. Future changes in variances will be incorporated in subsequent revisions to this compendium.

The regional variances presented in this subsection—as examples only—are given in chronological order to allow for comparison with the general procedure outlined in Subsection 5.1.6.

### 5.1.7.1 Activities Prior to Sampling

1. In Region I, the Site Managers must submit an analytical request for each individual sampling event at least 1 week prior to its occurrence. The request is submitted to the EPA RPM, who forwards the request to the EPA RSCC personnel. This request confirms the previously scheduled sampling.

2. Regions I and VIII provide a supply of organic and inorganic traffic reports that are used as needed and that are replaced periodically. Region II supplies traffic reports on a trip-by-trip basis. Regions III and IV provide a supply of organic and inorganic traffic reports to major contractors. These reports are used as needed and are replaced periodically as the supply diminishes. All other contractors within Regions III and IV will receive traffic reports on a trip-by-trip basis, as needed.

3. In Region V, the RSCC ranks by priority the monthly sampling requests and indicates that sampling can occur. The contractor is responsible for scheduling the analysis through SMO.

4. In Region IX, the Site Managers communicate directly with the RSCC, providing them with the monthly CLP projections.

### 5.1.7.2 Sampling Activities

1. Regions I, III, V, VI, and VIII use sample tags supplied by the region. Region II does not supply sample tags, which necessitates the use of contractor sample labels. Region IX supplies sample labels; no tags are used. Dedicated major Region IV contractors use sample tags supplied by the region. All other Region IV contractors must supply their own tags according to the region's specifications.

2. The Region IV sample tag is filled out differently from the Region III sample tag. Exhibit 5-7 gives an example of completed tags from Regions III and IV.

3. The Region II chain-of-custody (COC) form is entirely different from the COC form used by the other regions. The Region I, III, IV, V, VIII, and IX COC forms are almost identical. Exhibits 5-4 and 5-5 show two types of forms.

4. Region IV requires that custody seals be put on each bottle, unless one can ensure custody, as in hand delivery situations. Regions I, II, III, and VI require custody seals on the outer shipping container only. Region IX requires custody seals on both the sample bottles and the outer shipping container. Regions V and VIII require custody seals on the outer shipping container, with an option to put seals on each sample container.

5. Region IV places the traffic report label on the sample tag and the sample bottle, whereas Regions I, II, III, V, VI, VIII, and IX place the label directly on the bottle.

6. When the regional supply of COC forms or sample tags is not available, the contractor may supply COC forms and sample labels. These contractor supplied materials must satisfy all regional requirements for these forms.

7. Sampling personnel in Region IX contact the RSCC rather than SMO with shipping information.

8. The Region V procedures manual is being updated and will be available in June 1987; examples of completed paperwork are shown in that manual.

### 5.1.7.3 Postsampling Activities

1. Regions II, VI, and IX conduct the validation of the laboratory data, whereas data from sampling conducted in Regions I and VIII are validated by the contractor. Both the contractor and the EPA validate the data generated in Regions III, IV, and V.

2. The contractor-CLP coordinators provide the RSCCs in Regions II and VI with blank sample numbers, duplicate sample numbers, and other pertinent sampling information needed by the data validators. This same information is provided by the SM in Region IX.

### 5.1.8 Information Sources

U.S. Environmental Protection Agency. *User's Guide to the Contract Laboratory Program*. Office of Emergency and Remedial Response. December 1986.

CH2M HILL. *REM/FIT Documentation Protocol for Region V*. May 1984.

U.S. Environmental Protection Agency. *Engineering Support Branch Standard Operating Procedures and Quality Assurance Manual*. Region IV, Environmental Services Division. 1 April 1986.

## 5.2 NONCONTRACT LABORATORY PROGRAM

### 5.2.1 Scope and Purpose

There is no formal noncontract laboratory program (non-CLP) run parallel to the Contract Laboratory Program. A noncontract laboratory is procured by a method other than going through the SMO.

This subsection discusses how to contact a non-CLP laboratory, the paperwork involved when submitting samples to such a laboratory, and the resolution of questions once the analyses have been completed.

### 5.2.2 Definitions

**Noncontract Laboratory**
A laboratory that works directly for a contractor rather than SMO.

### 5.2.3 Applicability

The procedures in this subsection apply to two situations: (1) the CLP does not have the capacity to accept a sample, or (2) the EPA grants an exemption to the CLP usage requirement. The use of CLP is not a requirement unless justified by the choice of DQO. There will be opportunities to use mobile laboratories, field screening protocols, subcontracted private laboratories, or EPA regional laboratories.

### 5.2.4 Responsibilities

Responsibilities are discussed in Subsection 5.2.6 on procedures. General responsibilities are as follows:

- Site Managers plan the sampling dates and analytical requirements; the EPA RPM approves.
- The project chemist and chemistry section manager prepare the invitation for bids and evaluate and choose qualified laboratories to receive the invitation. The SM and EPA RPM select the laboratory.
- Sampling personnel complete the required paperwork and contact the laboratory with shipping information.

### 5.2.5 Records

The following sample documentation is required (examples are given in Subsection 5.1.6):

- Sample tag or label
- Custody seal
- Chain-of-custody (COC) form

A sample tag or label is required for each bottle of sample collected, while each shipment requires custody seals and COC forms.

### 5.2.6 Procedures

The procedures in this subsection are presented in the chronological order used during a routine sampling episode; they are applicable to any type of analysis. Exhibit 5-1 summarizes the process from start to finish.

#### 5.2.6.1 Activities Before Sampling

The first four activities conducted for a non-CLP laboratory before sampling are identical to steps 1 through 4 in Subsection 5.1.6.1. These steps continue as follows:

5. Each RSCC is given a monthly allocation of sample slots from SMO, for which the RSCCs may submit samples for analysis. Sometimes a region has more samples for analysis than slots, in which case some sampling must be postponed or canceled. The RSCC notifies the contractor when such a situation arises. Likewise, there are times when SMO cannot find a laboratory to perform the requested analysis. This is especially true for SAS work. The RSCC once again notifies the contractor of the unavailability of a laboratory.

6. The SM evaluates the advantages between waiting until CLP space becomes available and sending the samples outside the CLP system and advises the EPA RPM. The EPA RPM is responsible for deciding which laboratory to use. The EPA regional laboratory may be available to analyze the samples, in which case the EPA laboratory is treated as a CLP laboratory and the procedures in Section 5.1 are followed. If the decision is to go outside CLP, the RSCC and its QA coordinator can be very helpful in choosing a properly qualified laboratory.

As an alternate to steps 1 through 6, the project team and EPA RPM may determine that CLP-level data are not necessary for all analyses. In situations that involve taking a large number of samples, possibly taking a number of "clean" samples, or gathering information that will clearly never be used in an enforcement action, the appropriate analytical procedures may be furnished either by field instrumentation, by mobile laboratories, by a temporary laboratory set up near the site, or by contracting the work to a local laboratory. (CLP laboratories may also be used if they have non-CLP capacity available.) Procurement of these analytical services follows the steps discussed below.

7. A laboratory is procured using a standard bidding process. The laboratories chosen to receive the invitation for bids (IFB) are usually approved by the EPA regional QA representative, as well as other qualified EPA personnel. The analytical protocol is specified in the bid package and conforms closely to CLP or other EPA-approved methods. CLP methods are preferred because of the QA requirements. Typically, IFBs are sent to at least three laboratories. The SM selects the laboratory with technical assistance from the EPA RSCC, if available. The EPA Headquarters Project Officer and/or Contracting Officer must approve the subcontract before work begins.

On state lead sites, the prime contractor subcontracts with the laboratory and separate IFBs are not sent. Several remedial engineering management (REM) contractors have the availability to use team member laboratories that have established costs for several analyses. These laboratories may also respond to SAS requests in the form of subcontract bids.

The analytical procedures, and the QA/QC and sample control procedures used by the non-CLP laboratory are included as part of the Quality Assurance Project Plan (QAPjP). Depending on the type of analysis to be performed (e.g., field screening using portable instruments), QA/QC procedures may be greatly simplified when compared to CLP requirements. Data validation will be less time consuming also. Specific procedures for local, temporary, or mobile laboratories vary widely; the SM must carefully review these procedures before contracting any work.

### 5.2.6.2 Sampling

1. During sample collection, the samplers complete the required paperwork before the sample shipment. Examples of properly completed forms are given in Exhibits 5-4 through 5-7. It should be noted that whenever a noncontract laboratory is used, the contractor sample number should be substituted for the traffic report number, since no traffic report forms are used.

2. The samplers call the laboratory when samples are shipped or if shipment is delayed for any reason. This call allows for immediate notification when samples do not arrive on time, and it facilitates sample tracking. For mobile laboratories, care must be exercised to prevent "flooding" the sample preparation or analytical capabilities of the laboratory. Daily meetings with the mobile laboratory are sometimes needed.

3. The designated copy of the COC form is sent to the laboratory with the samples. Standard EPA and DOT shipping procedures are followed.

### 5.2.6.3 Postsampling

1. When the laboratory finishes the analyses, a copy of the results is forwarded to the contractor. The project chemist contacts the laboratory if results do not arrive on time. Unlike at CLP laboratories, verbal reporting of unvalidated results can be obtained from contractor chosen or mobile laboratories. While the SM must be judicious in the use of these results, the rapid turnaround allows the SM to adjust the sampling plan and to more intelligently use CLP resources for full analyses.

2. Once the data are received, questions may arise regarding their interpretation. The project chemist is the primary laboratory contact to resolve such questions.

### 5.2.6.4 Residual Samples and Analytical Wastes

At EPA's direction, duplicate samples are often collected and stored for later use. These archived samples, the residuals of samples sent out for analyses, and some of the wastes generated during analyses are regulated by various federal regulatory programs. CLP laboratories will assume responsibility for sample residuals at the laboratories. However, the SM must make arrangements for the proper disposal of archived or residual samples at non-CLP laboratories.

#### 5.2.6.4.1 Regulatory Framework

Each major federal program has elements that are expected to apply to sample and laboratory operations. These elements are cited and discussed briefly in this subsection.

**RCRA:** The Resource Conservation and Recovery Act (RCRA) regulations apply only to those wastes designated as hazardous under 40 CFR 261.3. If a sample is not a solid waste as defined in 40 CFR 261.2 or if the sample is a solid waste but not designated as hazardous in 40 CFR 261.3, that sample is not regulated under RCRA.

Even hazardous waste samples as defined in 40 CFR 261.3 are exempt from RCRA regulation if the terms of paragraph 40 CFR 261.4(d) are met. Section 40 CFR 261.4(d) is presented in its entirety below.

40 CFR 261.4(d) Samples

(1) Except as provided in paragraph (d)(2) of this section, a sample of solid waste or a sample of water, soil, or air, which is collected for the sole purpose of testing to determine its characteristics or composition, is not subject to any requirements of this part, or Parts 262 through 267, or Part 270, or Part 124 of this chapter, or to the notification requirements of Section 3010 of RCRA, when:

(261.4(d) introductory paragraph amended by 48 FR 30115, June 30, 1983)

(i) The sample is being transported to a laboratory for the purpose of testing; or

(ii) The sample is being transported back to the sample collector after testing; or

(iii) The sample is being stored by the sample collector before transport to a laboratory for testing; or

(iv) The sample is being stored in a laboratory before testing; or

(v) The sample is being stored in a laboratory after testing but before it is returned to the sample collector; or

(vi) The sample is being stored temporarily in the laboratory after testing for a specific purpose (for example, until conclusion of a court case or enforcement action where further testing of the sample may be necessary).

(2) To qualify for the exemption in paragraph (d)(1)(i) and (ii) of this section, a sample collector shipping samples to a laboratory, and a laboratory returning samples to a sample collector must:

(i) Comply with DOT, U.S. Postal Service (USPS), or any other applicable shipping requirements; or

(ii) Comply with the following requirements if the sample collector determines that DOT, USPS, or other shipping requirements do not apply to the shipment of the sample:

(A) Assure that the following information accompanies the sample:

(1) The sample collector's name, mailing address, and telephone number;

(2) The laboratory's name, mailing address, and telephone number;

(3) The quantity of the sample;

(4) The date of shipment; and

(5) A description of the sample.

(B) Package the sample so that it does not leak, spill, or vaporize from its packaging.

(3) This exemption does not apply if the laboratory determines that the waste is hazardous but the laboratory is no longer meeting any of the conditions stated in paragraph (d)(1) of this section.

A section of the RCRA regulations recognizes that analytical laboratory operations could generate wastewater which is mixed with small amounts of listed toxic hazardous wastes. This section [40 CFR 261.3(a)(2)(iv)(E)] excludes such wastewater from the RCRA hazardous waste regulations if the wastewater discharge is subject to regulation under either Section 402 or Section 307(b) of the Clean Water Act (CWA) and if the calculated annualized average wastewater flow from the laboratory constitutes 1 percent or less of the flow into the headworks of the treatment facility. (This calculation does not apply to septic systems or any treatment system not regulated by Section 402 or 307(b) of the CWA.)

**CWA:** The Clean Water Act (CWA) regulates wastewater discharges to publicly owned treatment works (POTWs) under Section 307(b) and wastewater discharges to surface waters under Section 402. Therefore, if a laboratory discharges into a POTW system or a privately run wastewater treatment plant that discharges treated effluent under an NPDES permit, that laboratory is indirectly regulated under the CWA. As noted above, RCRA conditionally excludes laboratory wastewater from regulation when this indirect CWA authority exists. Laboratory managers should know, however, that industrial wastewater discharges into POTWs are usually monitored and regulated by local authorities, such as sewer districts. Even though no pretreatment standards currently exist on a national basis for analytical laboratories, the general industrial effluent requirements for a particular POTW system might apply to the laboratory's effluent. Compliance with the locally established requirements is necessary to satisfy the RCRA exclusion.

**CERCLA:** The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is designed to provide a framework for both planned and emergency responses to releases of hazardous substances into the environment. Laboratory analytical samples are often associated with defining and responding to situations that fall under CERCLA authority. However, CERCLA, SARA, and the National Contingency Plan (NCP) (40 CFR Part 300) are not explicit on the issue of how hazardous substance samples are to be managed. The NCP will be revised in July 1987 and may address the issue more fully.

As stated earlier, samples of hazardous waste (as defined by 40 CFR 261.3) are managed in accordance with 40 CFR 261.3 and 261.4. No such standards, exclusions, or limitations exist for hazardous substance samples. However, management of hazardous substance samples as if they were hazardous waste may be appropriate based on Section 104(c)(3)(B) of CERCLA, which requires that any offsite treatment, storage, or disposal of hazardous substances be conducted in compliance with Subtitle C of the Solid Waste Disposal Act.

### 5.2.6.4.2 Procedures

Hazardous waste samples must be handled in conformance with 40 CFR 261.4(d) to be excluded from RCRA regulation regarding administrative requirements for transport, storage, treatment, and disposal. Similarly, samples of solid waste that might be hazardous (i.e., for which the hazard determination has not yet been made) and samples of hazardous substances as defined by CERCLA may be handled in conformance with 40 CFR 261.4(d).

Conformance with 40 CFR 261.4(d) requires that these hazardous samples be returned to their generator for proper management after the analysis. This return should be specified as an agreed-upon last task in analytical contracts for hazardous samples if the SM wishes to avoid the effort entailed in treating the material as other than a sample. Without the RCRA sample exclusion, samples would require manifesting for shipment to the laboratory; the receiving facility would need to be a RCRA Treatment, Storage, and Disposal Facility (TSDF); and offsite ultimate disposal would require yet another manifest. The American Chemical Society has prepared a booklet titled "RCRA and Laboratories" that details these requirements.

Some samples received by laboratories are clearly not hazardous by RCRA or CERCLA definitions; other samples are determined by analysis to be nonhazardous. These samples are not required to be managed in accordance with the RCRA exclusion paragraph. However, before any nonhazardous samples are disposed of as part of laboratory solid refuse or wastewater, the state and local solid waste codes and industrial wastewater discharge codes should be examined to assure that their terms are being met. (Many sewer districts, for example, require that total oil and grease loading not exceed a noted maximum at the facility outfall. This might restrict the disposal of large nonhazardous oily samples from disposal through the sewers.) Even for these nonhazardous samples, it might be necessary to have contract conditions or additional fees to cover the disposal of samples.

To meet the requirements, laboratory and storehouse managers should develop a specific instruction list noting logging, disposition, and contractual standards for each type of sample and analytical waste. These specific instructions could differ appreciably from one laboratory to another because of local codes and the nature and size of the sanitary sewer system compared to laboratory contribution. The SM should have a clear understanding of the residual sample deposition before shipping samples to a laboratory or warehouse.

### 5.2.6.4.3 Analytical Wastes

During chemical analysis, various extracts, components, and mixtures are derived from samples to determine their character and composition. Typically, these analytically derived substances are small in volume, but are not totally used up in the actual analysis. The leftover substances then become what is referred to as analytically derived waste.

In some cases, analytical wastes are not hazardous wastes (as defined in RCRA) or hazardous substances (as defined in CERCLA). As such, these wastes are disposed of in accordance with state and local solid waste and industrial waste water discharge requirements. Typically, these wastes can be disposed of in the wastewater discharged from the laboratory to the sanitary sewer.

In some cases, however, analytical wastes might have been derived from listed hazardous wastes, or the chemicals used to obtain the derivative, could cause the waste to be classified as hazardous. In either case, RCRA regulations provide for such waste to be disposed of with laboratory wastewater if certain conditions are met. Wastes that are considered hazardous only because of a characteristic (ignitability, corrosivity, reactivity, or EP toxicity—see 40 CFR 261, Subpart C) are no longer hazardous once they are mixed to eliminate the characteristic. Mixing small volumes of analytical waste with the sanitary sewer flow would cause the waste to become so diluted that it no longer exhibits hazardous characteristics.

When analytically derived wastes are produced in such volume or concentration that the conditions specified in the RCRA regulations or the discharge limits for the sanitary sewer cannot be met by disposing of these wastes with laboratory wastewater, other arrangements will need to be made.

### 5.2.7 Region-Specific Variances

The regional variances associated with the non-CLP are the same as for the CLP and can be found in Subsection 5.1.7.

### 5.2.8 Information Sources

American Chemical Society, Task Force on RCRA. "RCRA and Laboratories." Department of Government Relations and Science Policy, 1155 16th Street, NW, Washington, DC 20036. September 1986.

CH2M HILL. *REM/FIT Documentation Protocol for Region V.* May 1984.

U.S. Environmental Protection Agency. *Engineering Support Branch Standard Operating Procedures and Quality Assurance Manual.* Region IV, Environmental Services Division. 1 April 1986.

U.S. Environmental Protection Agency. *User's Guide to the Contract Laboratory Program.* Office of Emergency and Remedial Response. December 1986.

# SECTION 6

# SAMPLE CONTAINERS, PRESERVATION AND SHIPPING

**Note:** This section is presented by topic for greater clarity.

## 6.1 SAMPLE CONTAINERS AND PRESERVATION

### 6.1.1 Scope and Purpose

This subsection describes the sample containers and the preservatives used for environmental and hazardous samples collected at waste sites. The procedures described meet Contract Laboratory Program (CLP) requirements and analytical procedures. Periodic updates and changes are detailed in amendments to the *User's Guide to the CLP*. To obtain further information or copies of the *User's Guide to the CLP*, contact the Sample Management Office (SMO) at 703/557-2490 or FTS 557-2490.

### 6.1.2 Definitions

**Low-Concentration Sample**
The contaminant of highest concentration is present at less than 10 parts per million (ppm). Examples include background environmental samples.

**Medium-Concentration Sample**
The contaminant of highest concentration is present at a level greater than 10 ppm and less than 15 percent (150,000 ppm). Examples include material onsite that is obviously weathered.

**High-Concentration Sample**
At least one contaminant is present at a level greater than 15 percent. Samples from drums and tanks are assumed to be high concentration unless information indicates otherwise.

**Routine Analytical Services (RAS)**
Analysis of a soil or water sample on a 30- to 45-day turnaround time for a list of 126 organics, 23 metals, and cyanide.

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

### 6.1.3 Applicability

The procedures described in Section 6 apply to samples collected for routine, as well as for special analytical services. They are to be followed when the samples are being sent to either a CLP laboratory or a noncontract laboratory.

### 6.1.4 Responsibilities

Responsibilities are described in Subsection 6.1.6. General responsibilities are assigned as follows:

- The SM (and project team) will determine the number and type of samples to be collected and the analyses to be performed; the EPA RPM approves work plan.
- Equipment manager will obtain the proper grades and types of preservatives and bottles.
- Sampling personnel will collect a representative sample and, if necessary, will add the proper sample preservatives (as defined herein) once the samples have been collected.

### 6.1.5 Records

The preservatives used for each bottle are recorded on the sample tag or label. Tags and labels are discussed in Subsection 6.2.6; examples of completed tags are shown in Subsection 5.1.6. Shipping records are maintained as part of the chain-of-custody documentation. (See Section 4 of this compendium.)

### 6.1.6 Procedures

The procedures in this subsection are presented in the chronological order of a typical sampling episode. Exhibit 6-1 summarizes the sampling process. Procedures presented here are generic; an approach to regional differences is presented in Subsection 6.1.7.

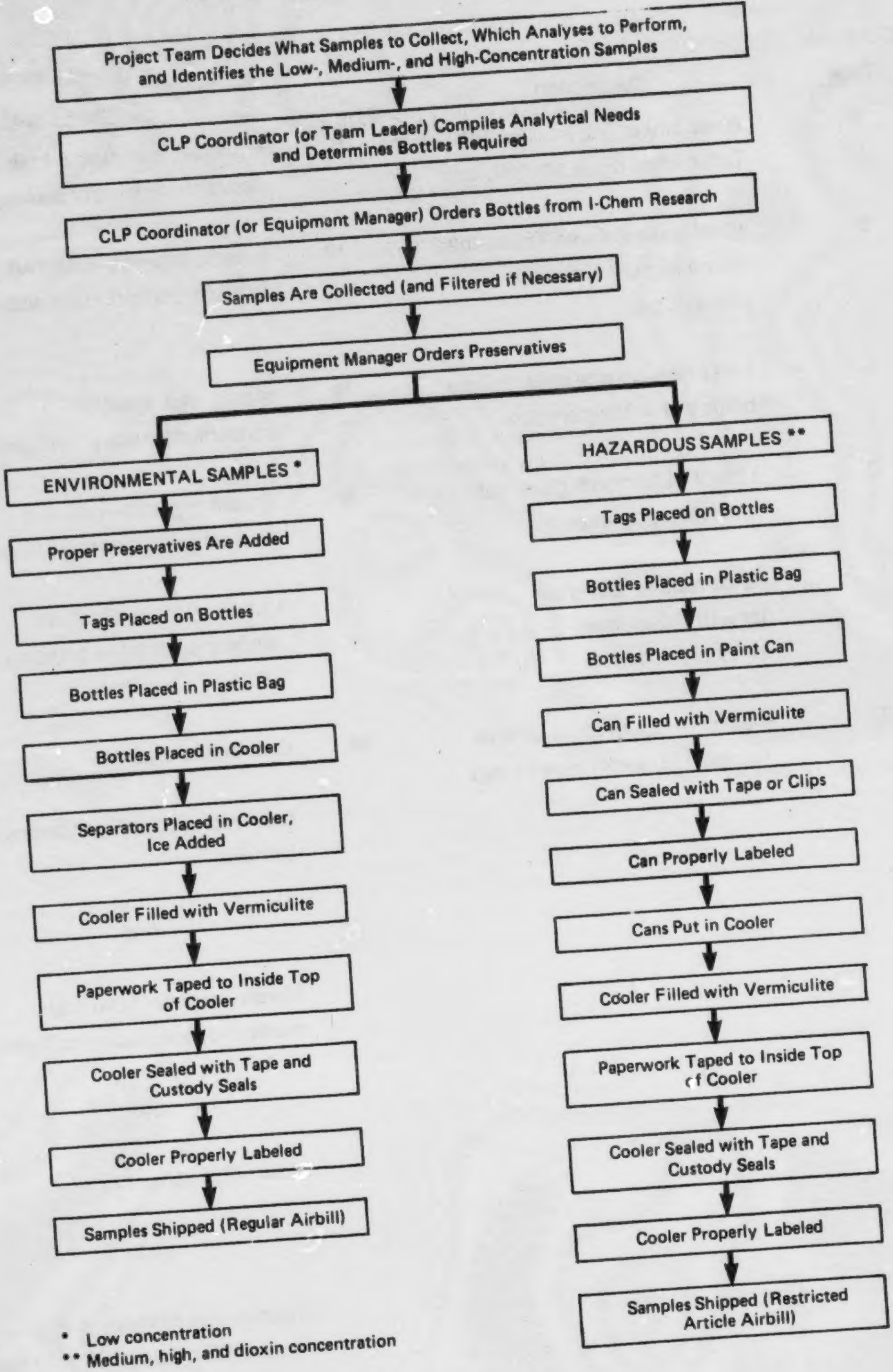
#### 6.1.6.1 Activities Before Sampling

1. In addition to the activities detailed in Subsection 5.1.6.1 for reserving laboratory space, the SM (or designee) obtains sample bottles by contacting an EPA authorized requester at the Regional Sample Control Center (RSCC) who orders the necessary bottles. (Currently, I-Chem Research in California (415/782-3905), runs the official bottle repository for the Superfund program.) Exhibit 6-2 lists the types of bottles available from the repository and summarizes the bottle requirements for each class of sample (as presented in the *User's Guide to the CLP*, December 1986).

2. At the same time, the SM (or designee) must order the chemicals necessary to preserve the samples once they are collected. The chemicals that may be used include the following:

   - Nitric acid, American Chemical Society (ACS) grade, 16N
   - Sodium hydroxide, ACS grade, pellets
   - Sulfuric acid, ACS grade, 37N
   - Hydrocholoric acid, ACS grade, 12N
   - Sodium thiosulfate, ACS grade, crystalline
   - Mercuric chloride, ACS grade, powder

## Exhibit 6-1
## TYPICAL SAMPLING PROCEDURES


Project Team Decides What Samples to Collect, Which Analyses to Perform, and Identifies the Low-, Medium-, and High-Concentration Samples
CLP Coordinator (or Team Leader) Compiles Analytical Needs and Determines Bottles Required
CLP Coordinator (or Equipment Manager) Orders Bottles from I-Chem Research
Samples Are Collected (and Filtered if Necessary)
Equipment Manager Orders Preservatives
ENVIRONMENTAL SAMPLES *
Proper Preservatives Are Added
Tags Placed on Bottles
Bottles Placed in Plastic Bag
Bottles Placed in Cooler
Separators Placed in Cooler, Ice Added
Cooler Filled with Vermiculite
Paperwork Taped to Inside Top of Cooler
Cooler Sealed with Tape and Custody Seals
Cooler Properly Labeled
Samples Shipped (Regular Airbill)
HAZARDOUS SAMPLES **
Tags Placed on Bottles
Bottles Placed in Plastic Bag
Bottles Placed in Paint Can
Can Filled with Vermiculite
Can Sealed with Tape or Clips
Can Properly Labeled
Cans Put in Cooler
Cooler Filled with Vermiculite
Paperwork Taped to Inside Top of Cooler
Cooler Sealed with Tape and Custody Seals
Cooler Properly Labeled
Samples Shipped (Restricted Article Airbill)

* Low concentration

** Medium, high, and dioxin concentration

## Exhibit 6-2
## SAMPLE BOTTLES AVAILABLE FROM THE REPOSITORY

| Container Type | Description | No. Per Carton | Used for RAS Sample Type* |
|---|---|---|---|
| A | 80-oz amber glass bottle with Teflon-lined black phenolic cap | 6 | Extractable organics--Low-concentration water samples |
| B | 40-ml glass vial with Teflon-lined silicon septum and black phenolic cap | 72 | Volatile organics--Low-and medium-concentration water samples |
| C | 1-liter high-density polyethylene bottle with white poly cap | 42 | Metals, cyanide--Low-concentration water samples |
| D | 120-ml wide-mouth glass vial with white poly cap | 72 | Volatile organics--Low-and medium-concentration soil samples |
| E | 16-oz wide-mouth glass jar with Teflon-lined black phenolic cap | 48 | Metals, cyanide--Medium-concentration water samples |
| F | 8-oz wide-mouth glass jar with Teflon-lined black phenolic cap | 96 | Extractable organics<br>Low- and medium- concentration soil samples<br>and<br>Metals, cyanide--Low- and medium-concentration soil samples<br>and<br>Dioxin--Soil samples<br>and<br>Organics and inorganics--High-concentration liquid and solid samples |

## Exhibit 6-2
(continued)

| Container Type | Description | No. Per Carton | Used for RAS Sample Type* |
|---|---|---|---|
| G | 4-oz wide-mouth glass jar with Teflon-lined black phenolic cap | 120 | Extractable organics--Low- and medium-concentration soil samples<br>and<br>Metals, cyanide--Low- and medium-concentration soil samples<br>and<br>Dioxin--Soil samples<br>and<br>Organic and inorganic--High-concentration liquid and solid samples |
| H | 1-liter amber glass bottle with Teflon-lined black phenolic cap | 24 | Extractable organics--Low-concentration water samples |
| J | 32-pz wide-mouth glass jar with Teflon-lined black phenolic cap | 36 | Extractable organics--Medium-concentration water samples |
| K | 4-liter amber glass bottle with Teflon-lined black phenolic cap | 4 | Extractable organics--Low-concentration water samples |

---

* This column specifies the only type(s) of samples that should be collected in each container.

### 6.1.6.2 Sampling Activities

1. The samplers collect representative aliquots of each medium and place them in the appropriate sample jars as described in Exhibit 6-2.

2. The samplers preserve the low-concentration water samples as follows:

- Nitric acid ($HNO_3$) is added to the TCL metals bottle until the pH is less than 2 (2 ml of 1+1 is usually sufficient).

**Note:** Analysis for dissolved metals requires filtration of the sample before preservation; however, the preservation method is the same for both dissolved and total metals.

For the cyanide aliquot, the following guidelines should be followed:

- Test a drop of sample with potassium iodide-starch test paper (KI-starch paper); a blue color indicates the presence of oxidizing agents and the need for treatment. Add ascorbic acid, a few crystals at a time, until a drop of sample produces no color on the indicator paper. Then add an additional 0.6g of ascorbic acid for each liter of sample volume.

- Test a drop of sample on lead acetate paper previously moistened with acetic acid buffer solution. Darkening of the paper indicates the presence of $S^{2-}$. If $S^{2-}$ is present, add powdered cadmium carbonate until a drop of the treated solution does not darken the lead acetate test paper and then filter the solution before raising the pH for stabilization.

- Preserve samples with 2 ml of 10 N sodium hydroxide per liter of sample (pH $\geq$ 12).

- Store the samples so that their temperature is maintained at 4°C until the time of analysis.

- Samples to be analyzed for TCL organics are packed in ice and shipped to the laboratory with ice in the cooler.

The following RAS samples do not require preservatives:

- Soil or sediment samples

- Medium or high-concentration water samples

Exhibit 6-3 lists the preservatives used for frequently requested special analytical services.

3. The samples are shipped to the laboratory for analysis.

## Exhibit 6-3
## SAMPLE PRESERVATION REQUIREMENTS

| Analysis | Preservation |
|---|---|
| Acidity | Cool, 4°C |
| Alkalinity | Cool, 4°C |
| Bicarbonate | Cool, 4°C |
| Carbonate | Cool, 4°C |
| Chloride | None |
| Chemical Oxygen Demand (COD) | $H_2SO_4$ to pH $<2$, Cool, 4°C |
| EP toxicity | None |
| Nitrogen | |
| Ammonia | $H_2SO_4$ to pH $<2$, Cool, 4°C |
| Kjeldahl, total | $H_2SO_4$ to pH $<2$, Cool, 4°C |
| Nitrate | $H_2SO_4$ to pH $<2$, Cool, 4°C |
| Nitrite | Cool, 4°C |
| Oil and grease | $H_2SO_4$ to pH $<2$, Cool, 4°C |
| Sulfate | Cool, 4°C |
| Solids | |
| Total dissolved | Cool, 4°C |
| Total suspended | Cool, 4°C |
| Total Organic Carbon (TOC) | $H_2SO_4$ or HCl to pH $<2$, Cool, 4°C |
| Total Organic Halogen (TOH or TOX) | Several crystals of sodium thiosulfate if chlorine is present, cool, 4°C |

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Refer to RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (TEGD) and SW-846 for additional information on sample preservation, recommended containers, maximum holding times, and volume requirements. EPA's Characterization of Hazardous Waste Sites, Vols. 1 and 2, and Soil Sampling QA User's Guide contain information regarding holding time criteria for soil or sediment.

### 6.1.7 Region-Specific Variances

The regional variances listed in this subsection are in chronological order to allow for easy comparison with the generic procedure described in Subsection 6.1.6. Because this information may become dated rapidly, the user should contact the EPA RPM or RSCC to get full details on current regional practices or requirements before planning sampling activities. Future changes in variances will be incorporated in subsequent revisions to this compendium.

#### 6.1.7.1 Presampling Activities

Regional variances during the presampling phase will be discussed in Revision 01.

#### 6.1.7.2 Sampling Activities

1. Region IV requires that samples collected for volatile analysis be preserved with hydrochloric acid. Four drops of concentrated HCl are added to each VOA vial before the vial is filled with the sample.

2. Region V preserves the metals sample with 5 ml of nitric acid. In addition, Region V uses a 10 normal sodium hydroxide solution rather than sodium hydroxide pellets.

### 6.1.8 Information Sources

U.S. Environmental Protection Agency. *The User's Guide to the Contract Laboratory Program.* Office of Emergency and Remedial Response. December 1986.

*Federal Register.* Vol. 49, No. 209, p. 43260. 28 October 1984.

U.S. Environmental Protection Agency. *Engineering Support Branch Standard Operating Procedures and Quality Assurance Manual.* Region IV, Environmental Services Division. 1 April 1986.

CH2M HILL. *REM/FIT Documentation Protocol for Region V.* May 1984.

## 6.2 PACKAGING, LABELING AND SHIPPING

### 6.2.1 Scope and Purpose

This subsection describes the packaging, labeling and shipping used for environmental and hazardous samples collected at a waste site.

### 6.2.2 Definitions

The definitions are the same as those in Subsection 6.1.2.

### 6.2.3 Applicability

The procedures described in this subsection apply to samples collected at a waste site. They must be followed whether shipping to a CLP laboratory or a noncontract laboratory.

The shipment of hazardous materials is governed by the Transportation Safety Act of 1974. Following is a list of references that detail the regulations:

- Title 49 CFR
  - Parts 100-177 – Shipper Requirements and Hazardous Material Table
  - Parts 178-199 – Packaging Specifications
  - Section 262.20 – Hazardous Waste Manifest
- International Civil Aviation Regulations (ICAO)
  - Technical Instructions for the Safe Transport of Dangerous Goods by Air (lists mandatory international and optional domestic regulations)
- International Air Transport Association (IATA)
  - Dangerous Goods Regulations (This tariff incorporates 49 CFR, ICAO, and additional IATA regulations. Most international and domestic airlines belong to IATA and require conformance to all applicable regulations.)
- Tariff BOE-6000-D (reprint of 49 CFR with updates)

### 6.2.4 Responsibilities

Detailed responsibilities are described in the procedures subsection. General responsibilities are assigned as follows:

- Site Managers will state, to the best of their knowledge, whether samples planned for collection are environmental or hazardous samples.
- Equipment manager will procure shipping supplies (metal cans, shipping labels, vermiculite, etc.) using RSCC whenever needed.
- Sampling personnel will properly label and package the samples.

### 6.2.5 Records

The user should refer to Section 4 for discussion of the records associated with sample collection and chain-of-custody forms.

The following records are associated with the labeling and shipping process:

- Sample tag or label
- Traffic report label

- Custody seal
- Chain-of-custody (COC) form
- Bill of lading (airbill or similar document)

Examples of the first four documents are given in Subsections 4.6 and 5.1.6; an example of an airbill is given in Subsection 6.2.

## 6.2.6 Procedures

The procedures described in this subsection are carried out after the sample preservation described in Subsection 6.1.6.2. They are generic in nature; an approach to regional differences is presented in Subsection 6.2.7.

### 6.2.6.1 Environmental Samples

Low-concentration samples are defined as environmental samples and should be packaged for shipment as follows:

1. A sample tag is attached to the sample bottle. Examples of properly completed sample tags are given in Exhibit 5-7.

2. All bottles, except the volatile organic analysis (VOA) vials, are taped closed with electrical tape (or other tape as appropriate). Evidence tape may be used for additional sample security.

3. Each sample bottle is placed in a separate plastic bag, which is then sealed. As much air as possible is squeezed from the bag before sealing. Bags may be sealed with evidence tape for additional security.

4. A picnic cooler (such as a Coleman or other sturdy cooler) is typically used as a shipping container. In preparation for shipping samples, the drain plug is taped shut from the inside and outside, and a large plastic bag is used as a liner for the cooler. Approximately 1 inch of packing material, such as asbestos-free vermiculite, perlite, or styrofoam beads, is placed in the bottom of the liner. Other commercially available shipping containers may be used. However, the use of such containers (cardboard or fiber boxes complete with separators and preservatives) should be specified in the sampling plan and approved by the EPA RSCC if CLP is used.

5. The bottles are placed in the lined picnic cooler. Cardboard separators may be placed between the bottles at the discretion of the shipper.

6. Water samples for low or medium-level organics analysis and low-level inorganics analysis must be shipped cooled to 4°C with ice. No ice is to be used in shipping inorganic low-level soil samples or medium / high-level water samples, or organic high-level water or soil samples, or dioxin samples. Ice is not required in shipping soil samples, but may be utilized at the option of the sampler. All cyanide samples, however, must be shipped cooled to 4°C.

7. The lined cooler is filled with packing material (such as asbestos-free vermiculite, perlite, or styrofoam beads), and the large inner (garbage bag) liner is taped shut. Sufficient packing material should be used to prevent sample containers from making contact during shipment. Again, evidence tape may be used.

8. The paperwork going to the laboratory is placed inside a plastic bag. The bag is sealed and taped to the inside of the cooler lid. A copy of the COC form should be included in the paperwork sent to the laboratory. Exhibit 5-4 gives an example of a properly completed COC form. The last block on the COC form should indicate the overnight carrier and airbill number. The airbill must be filled out before the samples are handed over to the carrier. The laboratory should be notified if another sample is being sent to another laboratory for dioxin analysis, or if the shipper suspects that the sample contains any other substance for which the laboratory personnel should take safety precautions.

9. The cooler is closed and padlocked or taped shut with strapping tape (filament-type).

10. At least two signed custody seals are placed on the cooler, one on the front and one on the back. Additional seals may be used if the sampler or shipper thinks more seals are necessary. Exhibit 5-6 gives an example of the two types of custody seals available.

11. The cooler is handed over to the overnight carrier, typically Federal Express. A standard airbill is necessary for shipping environmental samples. Exhibit 6-4 shows an example of the standard Federal Express airbill.

#### 6.2.6.2 Hazardous Samples

Medium- and high-concentration samples are defined as hazardous and must be packaged as follows:

1. A sample tag is attached to the sample bottle. Examples of properly completed sample tags are shown in Exhibit 5-7.

2. All bottles, except the VOA vials, are taped closed with electrical tape (or other tape as appropriate). Evidence tape may be used for additional security.

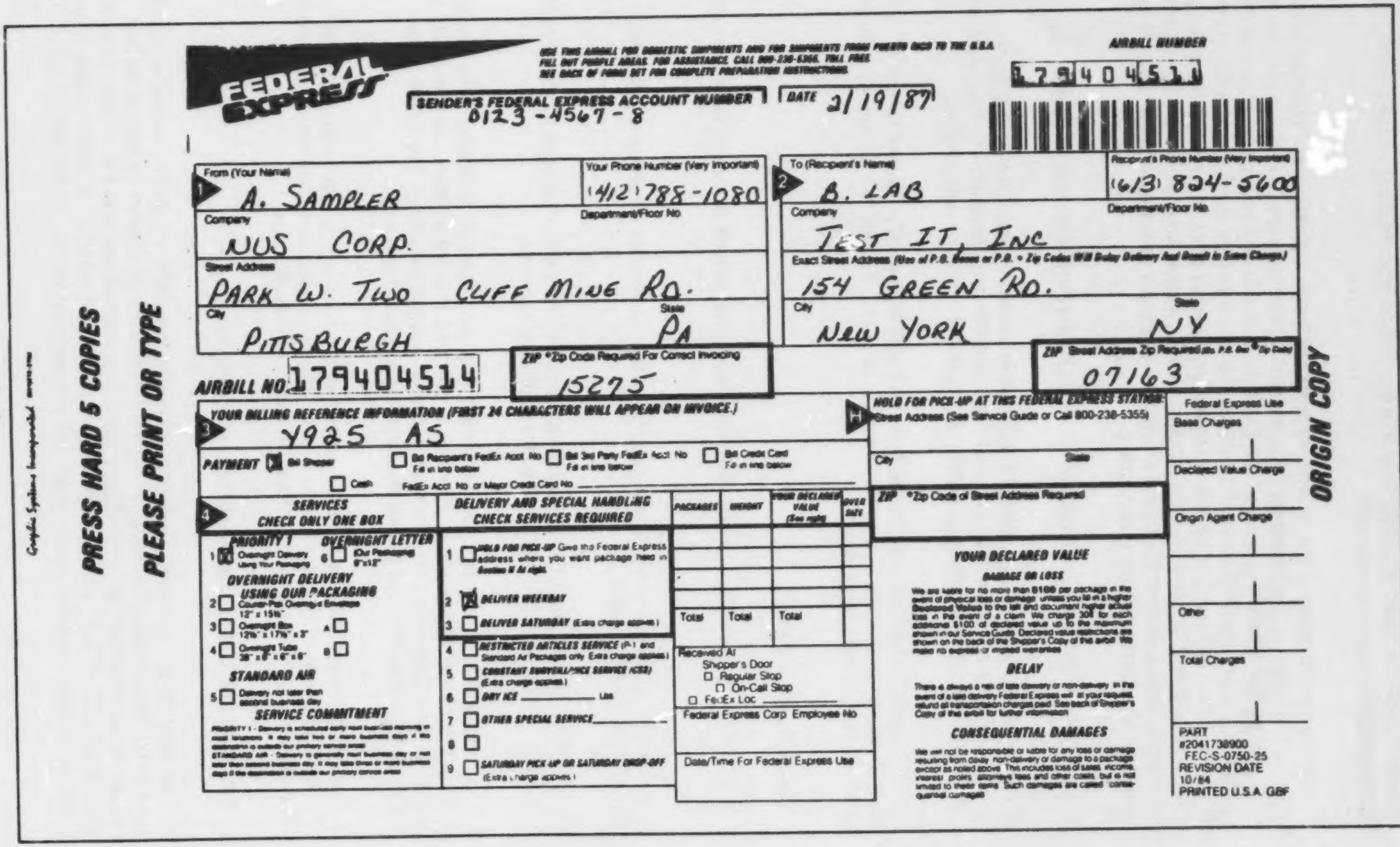
3. Each sample bottle is placed in a plastic bag, and the bag is sealed. For medium-concentration water samples, each VOA vial is wrapped in a paper towel, and the two vials are placed in one bag. As much air as possible is squeezed from the bags before sealing. Evidence tape may be used to seal the bags for additional security.

4. Each bottle is placed in a separate paint can, the paint can is filled with vermiculite, and the lid is fixed to the can. The lid must be sealed with metal clips or with filament or evidence tape; if clips are used, the manufacturer typically recommends six clips.

5. Arrows are placed on the can to indicate which end is up.

6. The outside of each can must contain the proper DOT shipping name and identification number for the sample. The information may be placed on stickers or printed legibly. A liquid sample of an uncertain nature is shipped as a flammable liquid with the shipping name "FLAMMABLE LIQUID, N.O.S." and the identification number "UN1993." A solid sample of uncertain nature is shipped as a flammable solid with the shipping name "FLAMMABLE SOLID, N.O.S."

# Exhibit 6-4
# STANDARD FEDERAL EXPRESS AIRBILL



FEDERAL EXPRESS

USE THIS AIRBILL FOR DOMESTIC SHIPMENTS AND FOR SHIPMENTS FROM PUERTO RICO TO THE U.S.A.
FILL OUT PURPLE AREAS. FOR ASSISTANCE, CALL 800-238-5355. TOLL FREE.
SEE BACK OF FORM SET FOR COMPLETE PREPARATION INSTRUCTIONS.

AIRBILL NUMBER 179404511

SENDER'S FEDERAL EXPRESS ACCOUNT NUMBER 0123 - 4567 - 8

DATE 2/19/87

1 From (Your Name) A. SAMPLER
Your Phone Number (Very Important) (412) 788-1080
Company NUS CORP.
Department/Floor No
Street Address PARK W. TWO CLIFF MINE RD.
City PITTSBURGH
State PA
ZIP *Zip Code Required For Correct Invoicing 15275

2 To (Recipient's Name) B. LAB
Recipient's Phone Number (Very Important) (613) 824-5600
Company TEST IT, INC
Department/Floor No.
Exact Street Address (Use of P.O. Boxes or P.O. + Zip Codes Will Delay Delivery And Result In Extra Charge.) 154 GREEN RD.
City NEW YORK
State NY
ZIP Street Address Zip Required (No P.O. Box *Zip Code) 07163

AIRBILL NO. 179404514

3 YOUR BILLING REFERENCE INFORMATION (FIRST 24 CHARACTERS WILL APPEAR ON INVOICE.) Y925 AS

PAYMENT ☒ Bill Shipper ☐ Bill Recipient's FedEx Acct No Fill in line below ☐ Bill 3rd Party FedEx Acct No Fill in line below ☐ Bill Credit Card Fill in line below
☐ Cash FedEx Acct No or Major Credit Card No ______

H HOLD FOR PICK-UP AT THIS FEDERAL EXPRESS STATION: Street Address (See Service Guide or Call 800-238-5355)
City
State
ZIP *Zip Code of Street Address Required

4 SERVICES
CHECK ONLY ONE BOX

PRIORITY 1
1 ☒ Overnight Delivery Using Your Packaging

OVERNIGHT LETTER
6 ☐ (Our Packaging) 9"x12"

OVERNIGHT DELIVERY USING OUR PACKAGING
2 ☐ Courier-Pak Overnight Envelope 12" x 15½"
3 ☐ Overnight Box 12¾" x 17½" x 3"
A ☐
4 ☐ Overnight Tube 38" x 6" x 6" x 6"
B ☐

STANDARD AIR
5 ☐ Delivery not later than second business day

SERVICE COMMITMENT

PRIORITY 1 - Delivery is scheduled early next business morning in most locations. It may take two or more business days if the destination is outside our primary service areas.
STANDARD AIR - Delivery is generally next business day or not later than second business day. It may take three or more business days if the destination is outside our primary service areas.

DELIVERY AND SPECIAL HANDLING
CHECK SERVICES REQUIRED

1 ☐ HOLD FOR PICK-UP Give the Federal Express address where you want package held in Section H at right.
2 ☒ DELIVER WEEKDAY
3 ☐ DELIVER SATURDAY (Extra charge applies.)
4 ☐ RESTRICTED ARTICLES SERVICE (P-1 and Standard Air Packages only. Extra charge applies.)
5 ☐ CONSTANT SURVEILLANCE SERVICE (CSS) (Extra charge applies.)
6 ☐ DRY ICE ______ Lbs
7 ☐ OTHER SPECIAL SERVICE ______
8 ☐
9 ☐ SATURDAY PICK-UP OR SATURDAY DROP-OFF (Extra charge applies.)

| PACKAGES | WEIGHT | YOUR DECLARED VALUE (See right) | OVER SIZE |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| Total | Total | Total | |

Received At
Shipper's Door
☐ Regular Stop
☐ On-Call Stop
☐ FedEx Loc ______

Federal Express Corp. Employee No

Date/Time For Federal Express Use

YOUR DECLARED VALUE

DAMAGE OR LOSS

We are liable for no more than $100 per package in the event of physical loss or damage unless you fill in a higher Declared Value to the left and document higher actual loss in the event of a claim. We charge 30¢ for each additional $100 of declared value up to the maximum shown in our Service Guide. Declared value restrictions are shown on the back of the Shipper's Copy of this airbill. We make no express or implied warranties.

DELAY

There is always a risk of late delivery or non-delivery. In the event of a late delivery Federal Express will, at your request, refund all transportation charges paid. See back of Shipper's Copy of this airbill for further information.

CONSEQUENTIAL DAMAGES

We will not be responsible or liable for any loss or damage resulting from delay, non-delivery or damage to a package except as noted above. This includes loss of sales, income, interest, profits, attorney's fees and other costs, but is not limited to these items. Such damages are called "consequential damages."

Federal Express Use
Base Charges
Declared Value Charge
Origin Agent Charge
Other
Total Charges

PART
#2041738900
FEC-S-0750-25
REVISION DATE
10/84
PRINTED U.S.A. GBF

ORIGIN COPY

PLEASE PRINT OR TYPE

PRESS HARD 5 COPIES

Graphic Systems Incorporated

and the identification number "UN1325." If the nature of the sample is known, 49 CFR-171-177 is consulted to determine the proper labeling and packaging requirements.

7. The cans are placed upright in a cooler that has had its drain plug taped shut inside and out, and the cooler has been lined with a garbage bag. Vermiculite is placed on the bottom. Two sizes of paint cans are used: half-gallon and gallon. The half-gallon paint cans can be stored on top of each other; however, the gallon cans are too high to stack. The cooler is filled with vermiculite, and the liner is taped shut.

8. The paperwork going to the laboratory is placed inside a plastic bag and taped to the inside of the cooler lid. A copy of the COC form, an example of which is shown in Exhibit 5-4, should be included in the paperwork sent to the laboratory. The sampler keeps one copy of the COC form. The laboratory should be notified if a parallel sample is being sent to another laboratory for dioxin analysis, or if the sample is suspected of containing any substance for which laboratory personnel should take safety precautions.

9. The cooler is closed and sealed with strapping tape. At least two custody seals are placed on the outside of the cooler (one on the front and one on the back). More custody seals may be used at the discretion of the sampler.

10. The following markings are placed on the top of the cooler:

- Proper shipping name (49 CFR 172.301)
- DOT identification number (49 CFR 172.301)
- Shipper's or consignee's name and address (49 CFR-172.306)
- "This End Up" legibly written if shipment contains liquid hazardous materials (49 CFR 172.312)

Other commercially available shipping containers may be used. The SM should ascertain that the containers are appropriate to the type of sample being shipped. The SM should clearly specify the type of shipping container to be used in the QAPjP.

11. The following labels are required on top of the cooler (49 CFR 172.406e):

- Appropriate hazard class label (placed next to the proper shipping name)
- "Cargo Aircraft Only" (if applicable as identified in 49 CFR 172.101)

12. An arrow symbol(s) indicating "This Way Up" should be placed on the cooler in addition to the markings and labels described above.

13. Restricted-article airbills are used for shipment. Exhibit 6-5 shows an example of a restricted article Federal Express airbill. The "Shipper Certification for Restricted Articles" section is filled out as follows for a flammable solid or a flammable liquid:

- Number of packages or number of coolers
- Proper shipping name: If unknown, use
  - Flammable solid, N.O.S., or
  - Flammable liquid, N.O.S.
- Classification; If unknown, use
  - Flammable solid or
  - Flammable liquid
- Identification number; if unknown, use
  - UN1325 (for flammable solids) or
  - UN1993 (for flammable liquids)
- Net quantity per package or amount of substance in each cooler
- Radioactive materials section (Leave blank.)
- Passenger or cargo aircraft (Cross off the nonapplicable. Up to 25 pounds of flammable solid per cooler can be shipped on a passenger or cargo aircraft. Up to 1 quart of flammable liquid per cooler can be shipped on a passenger aircraft, and up to 10 gallons of flammable liquid per cooler can be shipped on a cargo aircraft.)
- Name and title of shipper (printed)
- An emergency telephone number at which the shipper can be reached within the following 24 to 48 hours
- Shipper's signature

**Note:** The penalties for improper shipment of hazardous materials are severe; a fine of $25,000 and 5 years imprisonment can be imposed for each violation. The SM or designee is urged to take adequate precautions.

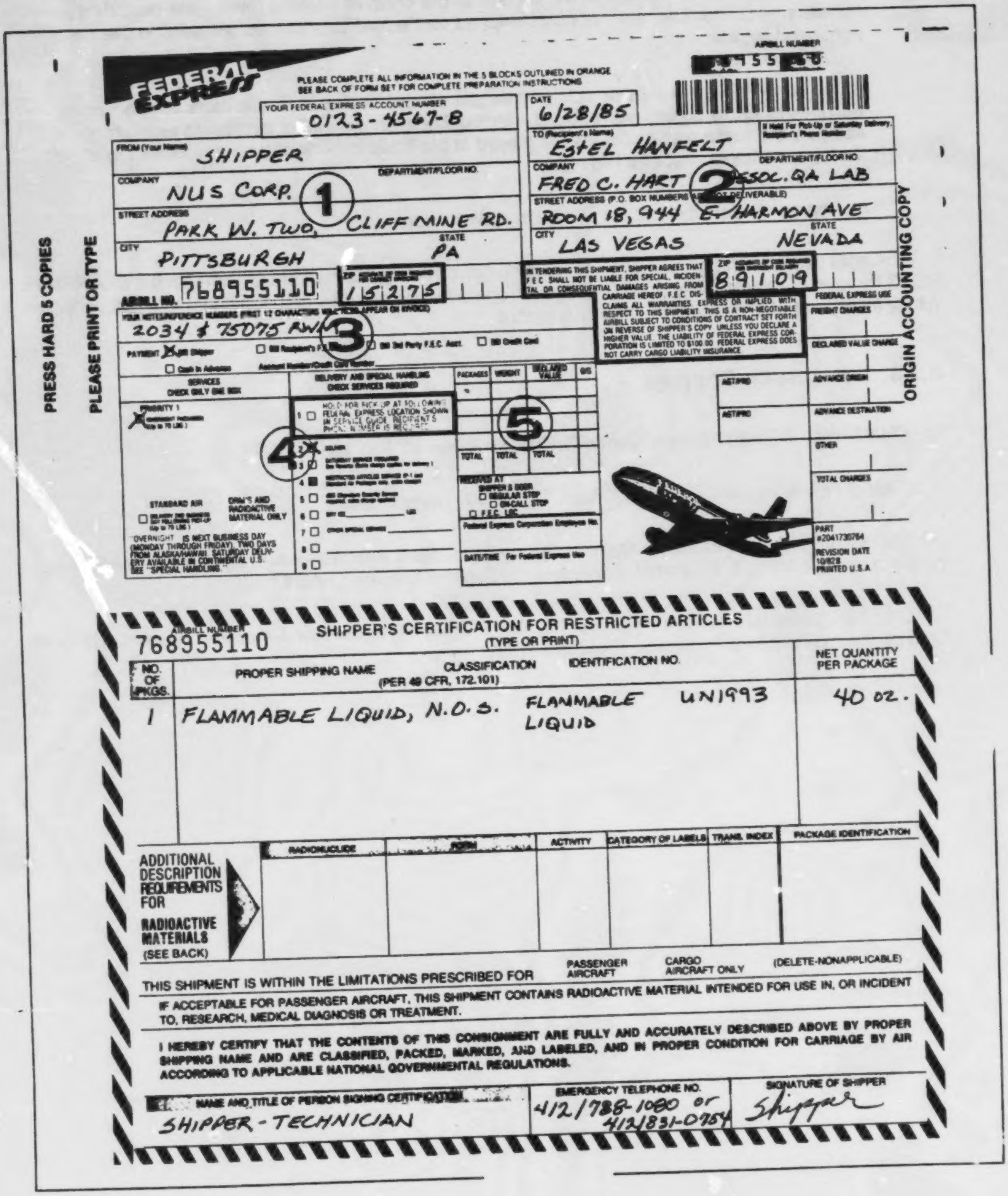
### 6.2.7 Regional Variances

There are no known regional variances for the shipment of hazardous samples. However, regional variances for the shipment of environmental samples (low concentration) are common. Information in a compendium on such variances can become dated rapidly. Thus, users are urged to contact the EPA RPM or the RSCC for the latest regional variances.

1. Region I includes the five-digit laboratory number of each sample in the "Remarks" section of the chain-of-custody form to act as a cross check on sample identification.

2. Separators must be placed between the bottles of samples shipped from a Region IV site. ESD also tapes the VOA vials and uses blue ice.

## Exhibit 6-5
## RESTRICTED ARTICLE FEDERAL EXPRESS AIRBILL



PRESS HARD 5 COPIES

PLEASE PRINT OR TYPE

ORIGIN ACCOUNTING COPY

FEDERAL EXPRESS

PLEASE COMPLETE ALL INFORMATION IN THE 5 BLOCKS OUTLINED IN ORANGE
SEE BACK OF FORM SET FOR COMPLETE PREPARATION INSTRUCTIONS

AIRBILL NUMBER [redacted]955[redacted]

YOUR FEDERAL EXPRESS ACCOUNT NUMBER: 0123-4567-8

DATE: 6/28/85

FROM (Your Name): SHIPPER

COMPANY: NUS CORP. ①

DEPARTMENT/FLOOR NO.

STREET ADDRESS: PARK W. TWO, CLIFF MINE RD.

CITY: PITTSBURGH

STATE: PA

ZIP: 15275

AIRBILL NO. 768955110

TO (Recipient's Name): ESTEL HANFELT

If Held For Pick-Up or Saturday Delivery, Recipient's Phone Number

COMPANY: FRED C. HART ② ASSOC.

DEPARTMENT/FLOOR NO.: QA LAB

STREET ADDRESS (P.O. BOX NUMBERS ARE NOT DELIVERABLE): ROOM 18, 944 E. HARMON AVE

CITY: LAS VEGAS

STATE: NEVADA

ZIP: 89109

IN TENDERING THIS SHIPMENT, SHIPPER AGREES THAT F.E.C. SHALL NOT BE LIABLE FOR SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING FROM CARRIAGE HEREOF. F.E.C. DISCLAIMS ALL WARRANTIES, EXPRESS OR IMPLIED, WITH RESPECT TO THIS SHIPMENT. THIS IS A NON-NEGOTIABLE AIRBILL SUBJECT TO CONDITIONS OF CONTRACT SET FORTH ON REVERSE OF SHIPPER'S COPY. UNLESS YOU DECLARE A HIGHER VALUE, THE LIABILITY OF FEDERAL EXPRESS CORPORATION IS LIMITED TO $100.00. FEDERAL EXPRESS DOES NOT CARRY CARGO LIABILITY INSURANCE.

YOUR NOTES/REFERENCE NUMBERS (FIRST 12 CHARACTERS WILL ALSO APPEAR ON INVOICE): 2034 $ 75075 RW ③

PAYMENT ☒ Bill Shipper ☐ Bill Recipient's F.E.C. Acct. ☐ Bill 3rd Party F.E.C. Acct. ☐ Bill Credit Card

☐ Cash in Advance   Account Number/Credit Card Number

SERVICES CHECK ONLY ONE BOX

PRIORITY 1
☒ OVERNIGHT PACKAGES (Up to 70 LBS.)

STANDARD AIR
☐ DELIVERY 2ND BUSINESS DAY FOLLOWING PICK-UP (Up to 70 LBS.)

ORM'S AND RADIOACTIVE MATERIAL ONLY

"OVERNIGHT" IS NEXT BUSINESS DAY (MONDAY THROUGH FRIDAY). TWO DAYS FROM ALASKA/HAWAII. SATURDAY DELIVERY AVAILABLE IN CONTINENTAL U.S. SEE "SPECIAL HANDLING."

DELIVERY AND SPECIAL HANDLING CHECK SERVICES REQUIRED ④

1 ☐ HOLD FOR PICK-UP AT FOLLOWING FEDERAL EXPRESS LOCATION SHOWN IN SERVICE GUIDE. RECIPIENT'S PHONE NUMBER IS REQUIRED
2 ☒ DELIVER
3 ☐ SATURDAY SERVICE REQUIRED
4 ■ RESTRICTED ARTICLES SERVICE
5 ☐
6 ☐ DRY ICE ________ LBS.
7 ☐ OTHER SPECIAL SERVICE ________
8 ☐ ________
9 ☐

| PACKAGES | WEIGHT | DECLARED VALUE | O/S |
|---|---|---|---|
| | ⑤ | | |
| TOTAL | TOTAL | TOTAL | |

RECEIVED AT
SHIPPER'S DOOR
☐ REGULAR STOP
☐ ON-CALL STOP
☐ F.E.C. LOC.

Federal Express Corporation Employee No.

DATE/TIME For Federal Express Use

FEDERAL EXPRESS USE

FREIGHT CHARGES

DECLARED VALUE CHARGE

ADVANCE ORIGIN

ADVANCE DESTINATION

OTHER

TOTAL CHARGES

AST/PRO

AST/PRO

PART #2041730764
REVISION DATE 10/828
PRINTED U.S.A.

AIRBILL NUMBER 768955110

### SHIPPER'S CERTIFICATION FOR RESTRICTED ARTICLES
(TYPE OR PRINT)

| NO. OF PKGS. | PROPER SHIPPING NAME | CLASSIFICATION (PER 49 CFR, 172.101) | IDENTIFICATION NO. | NET QUANTITY PER PACKAGE |
|---|---|---|---|---|
| 1 | FLAMMABLE LIQUID, N.O.S. | FLAMMABLE LIQUID | UN1993 | 40 OZ. |

ADDITIONAL DESCRIPTION REQUIREMENTS FOR RADIOACTIVE MATERIALS (SEE BACK)

| RADIONUCLIDE | FORM | ACTIVITY | CATEGORY OF LABELS | TRANS. INDEX | PACKAGE IDENTIFICATION |
|---|---|---|---|---|---|
| | | | | | |

THIS SHIPMENT IS WITHIN THE LIMITATIONS PRESCRIBED FOR PASSENGER AIRCRAFT CARGO AIRCRAFT ONLY (DELETE-NONAPPLICABLE)

IF ACCEPTABLE FOR PASSENGER AIRCRAFT, THIS SHIPMENT CONTAINS RADIOACTIVE MATERIAL INTENDED FOR USE IN, OR INCIDENT TO, RESEARCH, MEDICAL DIAGNOSIS OR TREATMENT.

I HEREBY CERTIFY THAT THE CONTENTS OF THIS CONSIGNMENT ARE FULLY AND ACCURATELY DESCRIBED ABOVE BY PROPER SHIPPING NAME AND ARE CLASSIFIED, PACKED, MARKED, AND LABELED, AND IN PROPER CONDITION FOR CARRIAGE BY AIR ACCORDING TO APPLICABLE NATIONAL GOVERNMENTAL REGULATIONS.

NAME AND TITLE OF PERSON SIGNING CERTIFICATION: SHIPPER - TECHNICIAN

EMERGENCY TELEPHONE NO.: 412/788-1080 or 412/831-0754

SIGNATURE OF SHIPPER: Shipper

3. Region V tapes the VOA vials and does not line the cooler with a plastic bag. Region V FIT indicates the OTR / ITR number, bottle lot numbers, sample concentrations, and matrix in the right-hand portion of the "Remarks" section of the chain-of-custody form. The custody seal numbers, airbill number, and "samples shipped via Federal Express" are included in the lower right-hand section.

4. Region VI does not tape sample bottles, put sample bottles in plastic bags, or line coolers with plastic. Glass bottles are wrapped with "bubble wrap" instead of cardboard separators. In addition, the traffic report stickers are placed at the liquid level on the sample bottles to allow the laboratories to check for leakage.

5. Region VIII does not put the sample in a plastic bag.

Because information on variances can become dated rapidly, the user should contact the EPA RPM or RSCC for current regional practices and requirements. Future changes and additional regional variances will be incorporated in Revision 01 of this document.

### 6.2.8 Information Sources

CH2M HILL. *REM/FIT Documentation Protocol for Region V.* May 1984.

*Code of Federal Regulations,* Title 49, Parts 171 to 177, Transportation.

U.S. Environmental Protection Agency. *Engineering Support Branch Standard Operating Procedures and Quality Assurance Manual.* Region IV, Environmental Services Division. 1 April 1986.

U.S. Environmental Protection Agency. *The User's Guide to the Contract Laboratory Program.* Office of Emergency and Remedial Response. December 1986.

# SECTION 7

# FIELD METHODS FOR RAPID SCREENING FOR HAZARDOUS MATERIAL

## 7.1 SCOPE AND PURPOSE

Section 7 provides an overview of current techniques used by some contractors to rapidly screen the hazardous waste material at waste sites. The section also describes the functions and capabilities of available analytical instrumentation and suggests some analytical protocols for mobile laboratories. The purpose of this section is not to provide standard operating procedures for rapid screening for hazardous material onsite or to establish performance criteria for direct-reading instruments or mobile laboratories. The purpose is to provide a narrative description of some approaches and techniques that have been used on certain projects. In Fall 1987, the Contract Laboratory Program (CLP) will publish a "Field Screening Methods Catalog" that will contain detailed discussions of field analytical methods. The CLP catalog will provide a consolidated reference for use by EPA, contractors, state and local agencies, and Potentially Responsible Parties (PRPs) who will be conducting field analysis. When this compendium is updated, it will reflect the information contained in the CLP catalog. The updated compendium will also contain any additional methods that were found useful by contractors but were not included in the catalog.

## 7.2 DEFINITIONS

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

## 7.3 APPLICABILITY

Field analysis involves the use of portable or transportable instruments that are based at or near a sampling site. Field analysis should not be confused with the process of obtaining total organic readings using portable meters.

Field analysis can provide data from the analysis of air, soil, and water samples for many Target Compound List (TCL) organic compounds, including volatiles, base neutral acid (BNA) extractable organics, and pesticides / PCBs. Inorganic analysis can also be conducted using portable atomic adsorption (AA) or other instruments.

The ability to assess data quality for field activities depends on the QA/QC steps taken in the process (e.g., documentation of blank injections, calibration standard runs, runs of qualitative standards between samples, etc.).

Field analytical techniques are used whenever the data quality objectives specify Level I and II analytical support as adequate.

The objective of Level I analysis is to generate data that are generally used in refining sampling plans and estimating the extent of contamination at the site. This type of support provides real-time data for health and safety purposes. Additional data that can effectively be obtained by Level I analyses include pH, conductivity, temperature, salinity, and dissolved oxygen for water (see Sections 8 and 10), as well as some measurement of contamination using various kits (see Subsection 7.6).

Level I analyses are generally effective for total vapor readings using portable photoionization or flame ionization meters that respond to a variety of volatile inorganic and organic compounds (see Section 15).

Level I analysis provides data for onsite, real-time total vapor measurement, evaluation of existing conditions, refinement of sampling location and health and safety evaluations. Data generated from Level I support are generally considered qualitative in nature, although limited quantitative data can also be generated. Data generated from this type of analysis provide the following:

- Identification of soil, water, air and waste locations that have a high likelihood of showing contamination through subsequent analysis
- Real-time data to be used for health and safety consideration during site reconnaissance and subsequent intrusive activities
- Quantitative data if a contaminant is known and the instrument is calibrated to that substance

The procedures discussed in this section have been used for several purposes including screening the site to determine the level of safety required for personnel working at the site; screening samples to determine which compounds, or groups of compounds, should be specified for further analysis, usually under the Contract Laboratory Program (CLP); and screening for characterizing material for removal and in refining the sampling plan to more precisely determine the number and type of samples to be taken. By using field screening, changes in sampling can occur while the field team is mobilized, rather than waiting for several months for data to return from CLP analysis. Field screening techniques, such as the removal of drums, lagoons, pits, ponds, and other waste sources, allows testing for compatibility and disposal category classification (Exhibit 7-1) before disposal.

Note: Because of the many safety factors to be considered when undertaking such screening, the SM should consult documents such as "Drum Handling Practices at Hazardous Waste Sites," EPA/600/2-86/013, January 1986.

## 7.4 RESPONSIBILITIES

Field screening generally consists of two phases:

- A field survey using instruments such as OVA meters or HNU detectors to analyze the ambient conditions onsite or to conduct limited analyses of samples (Level I on Data Quality Objectives rating; see Section 15)
- Mobile laboratory analyses to provide better qualitative and quantitative data upon which decisions can be made about site safety, CLP use and the sampling campaign (Level II on Data Quality Objectives rating)

The SM is responsible for defining the screening program and obtaining the proper equipment. The equipment manager and the mobile laboratory director are responsible for keeping the equipment in good

## Exhibit 7-1
## POTENTIAL ANALYTICAL REQUIREMENTS FOR DISPOSAL

1. Flammability
2. pH
3. Specific gravity
4. PCB analysis
5. Thermal content (BTU/lb)
6. Physical state at 70°F
7. Phases (layering in liquids)
8. Solids (%)
9. Hydrocarbon composition
10. Pesticide analysis
11. Sulfur content
12. Phenols
13. Oil and grease (%)
14. Water (%)
15. Viscosity
16. Organochlorine percentage
17. Metals analysis
    a. Liquids for soluble metals
    b. Solids extracted according to the EPA Toxicant Extraction Procedure (24 hr), which shows leachable metals
    c. Both liquid and solids checked for concentrations of the following metals:

        Arsenic
        Barium
        Cadmium
        Chromium
        Copper
        Lead
        Mercury
        Nickel
        Selenium
        Silver
        Zinc

18. Content checked for both free and total cyanide
19. Solids checked for solubility in water, sulfuric acid, and dimethyl sulfoxide

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Reprinted from Muller, Broad, and Leo, 1982. Exhibit originally printed in the Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites, 1982. Available from Hazardous Materials Control Research Institute, 9300 Columbia Blvd., Silver Spring, Maryland 20910.

working order. The field investigator(s) and the mobile laboratory analyst(s) are responsible for checking the equipment in the field and for verifying calibration and proper operation at the site.

## 7.5 RECORDS

Reporting is essential to thoroughly document technical methods and results. For screening of samples and field surveys, activity logs may be kept to record and document the results. Bound field notebooks with numbered pages should be used as the permanent record of results. Records should include field calibration procedures and duplicate readings. The equipment manager and the field analyst should keep records of equipment maintenance and field laboratory calibration and should make these records part of the permanent project file. The reader should refer also to Sections 4, 5, 6, and 17 of this compendium.

With a few exceptions, such as the mass-produced TAGA 6000E Mobile MS/MS System, mobile laboratories are each crafted differently. Accordingly, each mobile laboratory develops discrete standard operating and documentation procedures that are specific to the instrumentation, power and water supply, configuration, transportation arrangements, and housekeeping requirements for that laboratory. These specific procedures should be appended to the QAPjP and rigorously followed. The laboratory notebooks should document any deviations from the procedures or development of modifications to the procedures for site-specific needs.

Results from field screening are recorded in field or laboratory notebooks for the permanent record; tear sheets or carbonless forms are generally used to record results for the Site Manager's use before a report is written. (See Exhibit 7A-1 and 7A-3 for mobile laboratory reporting procedures.)

## 7.6 PROCEDURES

### 7.6.1 Inorganic Compounds

Exhibit 7-2 presents a list of typical inorganic compounds that a laboratory program might analyze for during a hazardous waste site investigation.

Several approaches are used to determine inorganic compounds. These approaches include the use of various field test kits as well as traditional and state-of-the-art instrumentation. Examples of field test kits include the Hach Hazardous Materials Detection Laboratory, the Hach COD kit, the Scintrex Atomic Absorption Spectrometer, indicator papers, portable wet chemistry test sets, and packaged test kits such as those produced by Chemetrics. Each of these kits includes a detailed set of instructions on use of the instruments and chemicals and on interpretation of results. A general discussion of the capabilities of some kits is presented below.

The kits offered by Hach and LaMotte Chemical include reagents to produce a colorimetric reaction with subsequent relative quantitative determination using a spectrophotometer, which is also in the kit. The Chemetrics test kits use self-filling ampoules that serve as disposable test cells. These ampoules contain a measured amount of reagent sealed under vacuum. These are colorimetric tests, and results are obtained through comparison with a color chart or through the use of a spectrophotometer or colorimeter. The Hach Hazardous Materials Laboratory (which is also usable for a limited number of organic compounds) is only class selective (e.g., heavy metals as a group) and is subject to interferences. The Hach kits and other colorimetric methods are best used in a survey mode analogous to that of the Organic Vapor Meters, because positive results would not be conclusive without supporting data.

**Exhibit 7-2**
**LISTING OF TYPICAL INORGANICS**

- Aluminum
- Antimony
- Arsenic
- Barium
- Beryllium
- Cadmium
- Calcium
- Chromium
- Cobalt
- Copper
- Cyanide
- Iron
- Lead
- Magnesium
- Manganese
- Mercury
- Nickel
- Potassium
- Selenium
- Silver
- Sodium
- Thallium
- Vanadium
- Zinc

The Scintrex Atomic Absorption Spectrometer is somewhat comparable to usual laboratory capabilities. The inclusion of Zeemann Effect background correction compensates for the lower optical performance, and the use of a tungsten furnace compares to the traditional laboratory instrument. The operator of the Atomic Absorption unit in the field must be well versed in sample preparation and sample handling techniques to avoid interference and contamination problems. The mobile Atomic Absorption unit appears to be well suited for overall field application from the standpoint of both mobility and analytical performance.

Although the process is expensive, inorganic analyses that use state-of-the art laboratory instruments such as an Inductively Coupled Plama (ICP) Spectrometer can be performed in a field screening mode. A protocol for inorganic analysis in mobile and fixed-base laboratories by ICP, flame, flameless, and cold-vapor atomic absorption techniques is attached as Exhibit 7A-3 in Appendix 7A. Heavy metals in solid samples can be analyzed by X-ray diffraction. An operating procedure for the Columbia Scientific X-Met 840 Analyzer is attached as Exhibit 7A-4 in Appendix 7A.

## 7.6.2 Organic Compounds

Exhibit 7-3 shows a typical list of organic compounds that the CLP analyzes for. Equipment for field analysis and screening of organic compounds falls into three broad categories:

- Portable, total organic vapor monitors
- Portable, selective organic instruments
- Mobile, selective organic instruments

### 7.6.2.1 Portable, Total Organic Vapor Monitors

Equipment in this category includes the HNU Model 101, the AID Models 710/712 and 580, and the Foxboro OVA 108/128. These instruments are essentially gas chromatographic detectors that continuously sample the ambient atmosphere. With the exception of two instruments, they respond to all organic vapors and are nonselective. The exceptions are the HNU Model 101 and the AID Model 580; both use a Photo Ionization Detector (PID). The PID does not respond to methane (or any other organic molecule with an ionization potential greater than the energy of the ionizing lamp). This selective response is advantageous, since methane is a common organic decomposition product and does not necessarily indicate the presence of toxic materials.

This type of equipment is already commonly used for health and safety as well as sample screening. Zero instrument response is a definitive result; it indicates an undetectable amount of organic vapors (toxic or otherwise) within the range of the instrument's ionizing lamp. However, a positive instrument response is not conclusive evidence of the presence of toxic materials, since the detector responds to both toxic and nontoxic organics. In addition to the selective response limitation, the organic vapor meters accept only vapor state samples. This equipment not only limits the sample type but also restricts the range of measurable compounds to the relatively high volatility materials.

Section 15 provides procedures for use of the equipment described above.

### 7.6.2.2 Portable, Selective Organic Instruments

These types of instruments include the Photovac 10A10, the AID Model 511, and the Foxboro OVA Century. While these instruments are portable, they are not as simple to use and transport as the total organic vapor instruments. If samples other than ambient air are to be analyzed, it would be more convenient to perform the analyses in a van, trailer, or building. The instruments listed above are isothermal gas chromatographs (GC). The Foxboro is designed to operate at either 0°C or 40°C, while the Photovac operates at ambient temperature. Thus, neither instrument is applicable for analysis of relatively nonvolatile compounds such as napthalene, phenol, or PCBs. The AID, while an isothermal GC, will maintain 200°C for 8 hours on battery power if preheated on AC power. This elevated temperature capability makes the AID suitable for analyzing PCBs and other semi-volatiles. The AID can be used by injecting a liquid sample, a process that is the most common method of sample introduction for semi-volatile organics analysis. The Photovac, the AID, and the Foxboro do not offer temperature programming or capillary column capability, both of which considerably enhance the selectivity of GCs.

This type of instrument is capable of identifying and quantitating organic compounds in relatively non-complex samples. The presence of large numbers of compounds in a sample can severely restrict the selectivity of this instrument. An example of a situation in which adequate selectivity would not be available is the analysis of phenanthrene or anthracene in the presence of oil. The large number of hydrocarbon compounds in the oil would obscure and interfere with the phenanthrene or anthracene.

One type of detector that is available for this type of equipment and that offers special selectivity is the electron capture detector (ECD), which exhibits high sensitivity for halogenated molecules. Thus, it is possible to analyze for chlorinated compounds such as PCBs in the presence of unhalogenated hydrocarbon compounds such as oils. Other compounds, such as phthalates, also cause a response with this detector, so interferences must always be considered. While this selectivity is advantageous when the compounds of interest are halogenated, this detector is not very useful for compounds such as benzene. This situation illustrates the type of considerations that should be used in selecting equipment appropriate for a given site.

### 7.6.2.3 Mobile, Selective Organic Instruments

This type of instrument ranges from GCs such as the Shimadzu Mini 2, the Hewlett-Packard 5890, the HNU Model 301, and the Unacon 810 through the Mass Spectrometric GC detectors to the tandem Mass Spectrometer / Mass Spectrometer (MS/MS) TAGA 3000 and 6000. These instruments require at least 120 volts of AC power, either from regular utility supplies or from generators. The GCs are amenable to

## Exhibit 7-3
## ORGANIC COMPOUNDS

### Volatile Fraction

Chloromethane
Bromomethane
Vinyl chloride
Chloroethane
Methylene chloride
Acetone
Carbon disulfide
1, 1-Dichloroethene
1, 1-Dichloroethane
Trans-1,2-dichloroethene
Chloroform
1, 2-Dichloroethane
2-Butanone (methyl ethyl ketone)
1, 1, 1-Trichloroethane
Carbon tetrachloride
Vinyl acetate
Bromodichloromethane
1, 1, 2, 2-Tetrachloroethane
1, 2-Dichloropropane
Trans-1, 3-dichloropropene
Trichloroethene
Dibromochloromethane
1, 1, 2-Trichloroethane
Benzene
Cis-1, 3-dichloropropene
2-Chloroethylvinylether
Bromoform
2-Hexanone (methly butyl ketone)
4-methyl-2-pentanone (methyl isobutyl ketone)
Tetrachloroethene
Toluene
Chlorobenzene
Ethylbenzene
Styrene
Total xylenes

### Semi-Volatile Compounds

Phenol
Bis(2-chloroethyl) ether
2-Chlorophenol
1, 3-Dichlorobenzene
1, 4-Dichlorobenzene
Benzyl alcohol
1, 2-Dichlorobenzene
2-Methylphenol
Bis (2-chloroisopropyl) ether
4-Methylphenol
N-nitroso-di-n-propylamine
Hexachloroethane
Nitrobenzene
Isophorone
2-Nitrophenol
2, 4-Dimethylphenol
Benzoic acid
Bis (2-chloroethoxy) methane
2, 4-Dichlorophenol
1, 2, 4-Trichlorobenzene
Naphthalene
Acenaphthene
2, 4-Dinitrophenol
4-Nitrophenol
Dibenzofuran
2, 4-Dinitrotoluene
2, 6-Dinitrotoluene
Diethylphthalate
4-Chlorophenyl-phenylether
Fluorene
4-Nitroaniline
4, 6-Dinitro-2-methylphenol
N-Nitrosodiphenylamine
4-Bromophenyl-phenylether
Hexachlorobenzene
Pentachlorophenol
Phenanthrene
Anthracene
Di-n-butylphthalate
Fluoranthene
Pyrene
Butylbenzylphthalate
3, 3'-Dichlorobenzidine

## Exhibit 7-3
## (continued)

### Semi-Volatile Compounds (continued)

- 4-Chloroaniline
- Hexachlorobutadiene
- 4-Chloro-3-methylphenol
- 2-Methylnapthalene
- Hexachlorobyclopentadiene
- 2, 4, 6-Trichlorophenol
- 2, 4, 5-Trichlorophenol
- 2-Chloronapthalene
- 2-Nitroaniline
- Dimethyl phthalate
- Acenaphthylene
- 3-Nitroaniline
- Benzo (a) anthracene
- Bis (2-ethylhexyl) phthalate
- Chrysene
- Di-n-octyl phthalate
- Benzo (b) fluoranthene
- Benzo (k) fluoranthene
- Benzo (a) pyrene
- Ideno (1, 2, 3-cd) pyrene
- Dibenzo (a, h) anthracene
- Benzo (g, h, i) perylene

### Pesticides

- Alpha-BHC
- Beta-BHC
- Delta-BHC
- Gamma-BHC (lindane)
- Heptachlor
- Aldrin
- Heptachlor epoxide
- Endosulfan 1
- Dieldrin
- 4,4'- DDE
- Endrin
- Endosulfan II
- 4, 4'-DDD
- Endosulfan sulfate
- 4, 4'-DDT
- Methoxychlor
- Endrin ketone
- Chlordane
- Toxaphene

### PCBs

- Aroclor-1016
- Aroclor-1221
- Aroclor-1232
- Arochlor-1242
- Arochlor-1248
- Aroclor-1254
- Aroclor-1260

transportation and setup facilities that are available onsite. The Mass Spectrometric detectors should be installed in dedicated mobile vans or trailers for transportation and operation, and the TAGA is transported and operated in a custom motor home with an integral generator.

Although the mobile GCs are more restricted than the portable GCs in the locations where they can be used, they offer significantly more potential selectivity. The ability to use capillary columns and to employ temperature programming greatly increases the resolution of chromatographic separations and enhances the selectivity of the analysis. Exhibit 7A-1 of Appendix 7A contains mobile laboratory protocols for organic analyses based on GC techniques.

The Unacon is a special device for sample preparation, which, in addition to purging and trapping aqueous samples, also facilitates the analyses of gases, soils, and sediments by gas chromatography. Solid sample materials (such as soil or dry sediment) can be loaded into a Unacon sample tube and heated to thermally desorb organics for GC analysis. The Unacon also provides for purge and trap and for direct solvent injection of liquid samples.

If a GC is interfaced to a Mass Spectrometric Detector, such as the Hewlett-Packard 5970 B or the Finnigan Ion Trap Detector (ITD), the resulting system will approach the selectivity of laboratory equipment. These mass-selective detectors are designed to operate with capillary column GCs and to include microcomputer-based data systems. While these data systems are compact and inexpensive, they can be fitted for high capacity storage that provides the capability to search mass spectral databases, such as the EPA/NIH Spectrum Library. The combination of a GC and a Mass Spectrometric Detector installed in a van offers the potential for a highly selective mobile-analysis capability.

The TAGA MS/MS unit has been used in field situations for which it provided a great deal of selectivity, although at a relatively high cost. When the situation warrants, the TAGA unit can provide exceptional specificity and sensitivity for the analysis of problem compounds such as 2,3,7,8-tetra-chlorodibenzo-p-dioxin (TCDD). The TAGA does not use a GC for initial separation of individual compounds. As the name implies, two mass spectrometers in tandem provide both compound separation and identification information within the same unit.

Effective use of these analytical instruments requires a high level of expertise and experience on the part of the analyst.

## 7.6.3 Class A Poisons

### 7.6.3.1 General

Class A poisons are defined as being extremely dangerous poisonous gases or liquids of which an extremely small amount of gas or vapor of the liquid mixed with air is dangerous to life.

Exhibit 7-4 lists 25 compounds that fall into this category. Sixteen of these compounds are listed by the Department of Transportation (DOT) as Class A poisons, and these compounds were selected for screening at waste sites in an EPA report entitled *Available Field Methods for Rapid Screening of Hazardous Waste Materials at Waste Sites*, Interim Report, Class A Poisons, December 1982. Determining the presence of Class A poisons is of interest to the SM because of the extremely strict requirements placed on the shipping of Class A poisons by DOT. The following paragraphs summarize the methods evaluated by EPA for screening Class A poisons.

## Exhibit 7-4
## CLASS A POISONS

Arsine
Bromoacetone
Carbonyl flouride
Chloropicrin
Cyanogen
Cyanogen chloride
Dichlorodiethyl sulfide
Ethyl bromoacetate
Ethyldichloroarsine
Germane
Hydrocyanic acid
Methyldichloroarsine
Nitric oxide
Nitrogen dioxide
Nitrogen tetroxide
Nitrogen trioxide
Phosgene
Diphosgene
Phosphine
Phenylcarbylamine chloride
Trichloroacetyl chloride
Tetrachlorodinitroethane
Allyl isothiocyanate
Dichloro-(2-chlorovinyl) arsine*
Hydrogen selenide

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* Lewisite blistering agent (mustard gas)

### 7.6.3.2 Screening Methods for Class A Poisons

The current state of the art for existing methods of general detection does not provide for the specific field screening of Class A poisons. It appears that a more promising approach is the specific detection method for each of the Class A poisons of interest. A convenient method for the field screening of specific volatile substances is the use of gas detection tubes. These tubes contain a granulated solid support, such as silica gel, with an adsorbed reagent that changes color in the presence of the species the reagent is designed to detect. A known quantity of sample gas is drawn through the detection tube, and the length of the resulting discoloration is read against a precalibrated scale to give the concentration of the species of interest. Interferences are common and can give erroneous results. The following summary of the literature describes the more promising systems for detection against reagents that might be used with the gas detection tube concept. Gas detection tubes for several of the Class A poisons are already commercially available. Colorimetric-indicating gas detection tubes are most useful in situations in which the contaminant is known or suspected; the tubes can reduce the possibility of interferences that produce erroneous results.

The EPA survey showed that 16 reagent detection systems lend themselves to field screening for hydrocyanic acid. Of the methods that were considered, four employed photometric analysis, while the other procedures used adsorption of hydrocyanic acid and/or the detector reagent on some type of solid support, such as silica gel, filter paper, or activated charcoal. Considering all factors, the commercially available Draeger detector tube for hydrocyanic acid appeared to offer the greatest potential for incorporation into field methodology. This tube has a detection range of 2.3 to 34 mg/m$^3$; acid gases such as hydrogen sulfide, hydrogen chloride, sulfur dioxide, and ammonia are retained in the precleanse layer.

Ten reagent systems were reported for the detection of arsine. Three methods involve photometric analysis; one is a titration procedure; the other six use adsorption on a solid support, as described above. The most promising of these methods for field screening appears to be the Draeger arsine detector tube, which has a detection range of 0.16 to 195 mg/m$^3$. Phosphine and antimony hydride are listed as positive interferences. It should be noted that phosphine is also classified as a Class A poison.

A total of 16 reagent detection systems were reported for the screening of ethyl and/or methyldichloroarsine. Two of these methods used a precipitate in the reagent solution as a positive result. Twelve methods used reagent-treated filter paper, while one used a coloration change made by marks of a treated crayon. The method that appears to be the most suitable for incorporation into a field test kit used a detector tube containing silica gel that has been impregnated with a mixture of zinc sulfate and molybdic acid. This tube offers direct and sensitive detection for alkyldichloroarsine. The detection limit of the reagent is given as 2.5 μg; other closely related organo-arsenic halides and hydrogen sulfide are given as positive interferences.

Eleven reagent detector systems could be used for field screening of mustard gas. There are two types of chemical warfare blistering agents: H (and its distillates HD and HT) and Lewisite. All are known by the general term "mustard gas." The most attractive of these methods for H compounds appears to be silica gel impregnated with auric chloride. According to the literature, a characteristic reddish-brown color appears in the presence of mustard gas.

Eleven potential field screening methods were found for the detection of dichloro-(2-chlorovinyl) arsine. The most promising of these methods appears to be that which uses Michler's thioketone (4,4'-bis (dimethylamino) thiobenzo phenone) as the reagent adsorbed on silica gel. This reagent system is currently used by the U.S. Army in its M256 gas detector kit for the detection of Lewisite.

Seven methods were identified that could be used for the field detection of cyanogen chloride. Two methods required photometric analysis, while one involved titration. The other four approaches used reagents adsorbed on some type of solid support. The most promising approach appears to be the use of the cyanogen chloride detector tube made by Draeger. This tube has a detection range of 0.64 to 12.8 mg/m$^3$. Cyanogen bromide is listed as a positive interference.

Nitric oxide and nitrogen dioxide can be detected by using the Draeger nitrous fumes detector tube. A total of 15 reagent systems were examined for the detection of nitric oxide and/or nitrogen dioxide. The Draeger tube method appears to be the most advantageous approach since both gases can be detected simultaneously and since the method is commercially available.

Eleven methods appeared suitable for adaptation to field screening for phosphine. One method involved titration; two used photometric analysis; the remaining eight methods used liquid reagents adsorbed on solid supports. The most promising method appears to be the use of the Draeger phosphine detector tube, which has a detection range of 0.14 to 5.68 mg/m$^3$. Antimony hydride and arsine, a Class A poi son, are given as positive interferences.

Only four reagent detection methods were found for the field screening of bromoacetone. The best approach for the detection of this compound appears to be a two-step method. Sodium nitroprusside is used as a detecting reagent for methyl ketones in the first step. An orange coloration of the sodium nitroprusside indicates the presence of this class of compounds. The second step is the detection of bromine using fuchsin-sulfurous acid test paper. A positive response is indicated when a violet color appears. When both of these tests are positive, bromoacetone is assumed to be present.

Sixteen reagent systems were examined for the detection of phosgene. Three methods require photometric analysis; one involves titration; the remaining approaches use a reagent on solid support. The best method appears to be the Draeger phosgene detector tube, which has a detection range of 0.17 to 6.2 mg/m$^3$. Carbonyl bromide and acetyl chloride are listed as positive interferences. Literature dealing with the detection of diphosgene stated that to use the Draeger tubes, the gas must be heated 300°C to 350°C to decompose it to phosgene, which is then detected by the above methods. Further testing will determine the necessity for this heat treatment.

One method was found for the specific detection of cyanogen. The reagents used for this test are 8-quinolinol and potassium cyanide, which turns red in the presence of this species. In addition, cyanogen may be converted to hydrogen cyanide or cyanogen chloride and can be detected as these substances.

Five detection means were reported for germanium. Two of these methods involved titrimetric analysis. Currently, the most promising approach for field detection appears to be the use of the reagent, hydroxyphenyl fluorene, which turns an orange color in the presence of germanium.

Only one method was reported for the detection of phenylcarbylamine chloride. This method uses Sudan red, ground chalk, and iron (III) chloride, which turns from red to green in the presence of phenylcarbylamine chloride. Sudan red is listed as a carcinogen.

The EPA report recommended that the above methods be evaluated in a laboratory as a means of screening for the Class A poison for which each system is designed.

## 7.7 REGION-SPECIFIC VARIANCES

Because field screening techniques are not completely standardized, the SM must prepare a detailed explanation of the methods to be used and the associated QA/QC procedures. This information is included in the QAPjP for review and approval by EPA.

## 7.8 INFORMATION SOURCES

CDM Federal Programs Corporation. *REM II Team Operating Procedures for X-Ray Fluorescence Analyzer.* April 1987.

*Equipment Available for Sample Screening and Onsite Measurements*. Technical Directive Document No. HQ-8311-04, Contract No. 68-01-6699. 30 May 1984.

NUS Corporation, Superfund Division. *Operating Guidelines Manual: Rapid Field Screening of Hazardous Substances.* Procedure 4.35 (Draft 1).

*REM/FIT Mobile Lab QA Procedure Development.* Technical Directive Document No. HQ-8505-04. 30 June 1985.

Roffman, H.K., and M.D. Neptune. *Field Screening of Samples From Hazardous Wastes*. Proceedings, Institute of Environmental Sciences. April 1985.

U.S. Environmental Protection Agency. *Available Field Methods for Rapid Screening of Hazardous Waste Materials at Waste Sites.* Interim Report, Class A Poisons, EPA Report No. 6001X-82-014. December 1982.

U.S. Environmental Protection Agency. *Drum Handling Practices at Hazardous Waste Sites*. EPA Report No. EPA/600/2-86-013. Cincinnati, Ohio: HWERL. August 1986.

# APPENDIX 7A

# PROTOCOLS, REPORTING, AND DELIVERABLES

The following sections discuss methodologies that have been used in screening samples on hazardous waste sites. The Site Manager (SM) should realize that these methodologies may not be suitable for all sites and may require extensive modification to meet the validation requirement of a specific region. Also, the methodologies used must be related to the data quality objectives of the project.

Exhibit 7A-1 presents protocols that have been used for analyses, reporting and deliverables for the mobile laboratory analysis of organic compounds for screening. Exhibit 7A-2 lists the estimated limits of detection for organics on the target compounds list. Exhibit 7A-3 presents the protocols to be followed for the mobile laboratory screening of inorganic trace elements and cyanide. Exhibit 7A-4 describes the operating procedure for XRF analysis of soils and tailings with the Columbia X-Met 840 Analyzer.

## HOLDING TIMES BEFORE ANALYSIS

Samples should be analyzed as soon as possible after sampling. One advantage to field analysis is rapid turn around, generally 24 hours, for most analyses. If samples are not analyzed immediately, the following holding times are suggested. Volatile organic analyses (VOAs) should be held no more than 7 days from sampling until analysis for water samples and no more than 10 days for soil or sediment samples. Base neutral acids (BNAs) and pesticides should be held no more than 5 days until extraction for water samples and no more than 10 days for soil or sediment samples. Samples must be refrigerated before analysis.

Inorganic samples should be preserved in the field according to EPA protocols found in the *User's Guide to the CLP*. The holding time for cyanides shall not exceed 24 hours.

### Exhibit 7A-1
### MOBILE LABORATORY PROTOCOLS FOR ORGANIC ANALYSES

## I. VOLATILE ORGANIC COMPOUNDS

A. Instrumentation for Water and Soil Sample Analyses

1. Tekmar purge and trap or equivalent
2. Temperature-programmed gas chromatograph equipped with flame-ionization detector
3. GC column
    - a. 60/80 Carbopack B/1 percent SP-1000 6 ft x 44mm I.D. glass-packed column

B. Water Sample Analysis

1. Adapted from Method 5030, SW-846, purge and trap
2. Calibration standard solution
    - a. Spike an aliquot of commercial (Supelco) standard mixture into 20 ml of reagent water and purge.
3. Analysis

**Exhibit 7A-1**
**(continued)**

a. Use calibration standard through purge and trap system.
  1) Once per site before sample analyses
  2) After every 20 sample analyses

b. Purge organic-free water blank (5 ml). solution analysis
  1) After every calibration standard solution analysis.
  2) After every 10 sample analyses

c. Perform corrective maintenance when calibration standard responses decrease by 20 percent of the initial calibration standard run; clean the injection port and the purge and trap appara

C. Soil / Sediment Sample Analysis

1. Adapted from Method 5030, SW-846, methanol extraction
2. Calibration standard solution preparation
    a. Spike aliquot of commercial (Supelco) standard mixture into 20 ml of reagent water and purge.
3. Extraction
    a. Place 1 g soil sample/10 methanol in a 40-ml glass Teflon-capped vial.
    b. Shake for 2 minutes.
    c. Allow solids to settle.
4. Analysis
    a. Use 400 μl extract injected/20 ml organic-free water (equivalent to 1 ppm limit of detection).
5. Quality control
    a. Use calibration standard through purge and trap system.
        1) Once per site before sample extract analyses
        2) After every 20 sample extract analyses
    b. Purge organic-free water blank (20 ml organic-free water containing the 400 μl methanol used for extraction).
        1) After every calibration standard analysis
        2) After every 10 sample extract analyses
        3) After any sample extracts that exceed 100 ppm
    c. Perform corrective maintenance when calibration standard responses decrease by 20 percent of the initial calibration standard run; clean the injection port and the purge and trap apparatus.

## II. SEMI-VOLATILE ORGANIC COMPOUNDS

A. Instrumentation for Water and Soil Sample Analyses

1. Base / neutral and acid extractable organic
    a. Temperature-programmed gas chromatograph equipped with a flame-ionization detector
2. Pesticides / PCBs
    a. Isothermal gas chromatograph equipped with an electron capture detector
3. GC column
    a. Base / neutral and acid extractable organics

**Exhibit 7A-1**
**(continued)**

1) Fused silica capillary column DB-5 or equivalent 30 mm x 0.32 mm, 1 micron film thickness

b. Pesticides / PCBs

1) 3 percent OV-1 on 80/100 Supelcoport 6 ft x 4 mm I.D. or equivalent

B. Water Sample Analysis

1. Pesticides / PCBs
   - a. Extraction
     - 1) Use 15 ml water sample/1.5 ml hexane in 20 ml disposable culture tube with cap (Teflon or aluminum foil liner).
     - 2) Shake for 2 minutes.
   - b. Analysis
     - 1) Inject 5 µl extract.
     - 2) Use detection limits 0.5 (for compounds such as lindane) to 20 ppb (for compounds such as Aroclor PCBs).
   - c. Calibration standard solution
     - 1) Pesticide mixture: lindane, 0.005 ng/µl; aldrin, 0.01 ng/µl; p-p'-DDT, 0.025 ng/µl
     - 2) PCBs: Aroclor 1254, 0.15 ng/µl
   - d. Quality control
     - 1) Inject calibration standard solution
       - a) Once per site before sample analysis
       - b) After every 20 sample extracts
     - 2) Inject solvent blank.
       - a) After each calibration standard solution analysis
       - b) After every 10 sample extract analyses.
     - 3) Spike (field) sample.
       - a) Spike water with spiking solution of lindane, 0.5 µl; aldrin,1.0 µg/l; p-p'-DDT, 2.5 µg/l
     - 4) Perform corrective maintenance when calibration response decreases 20 percent from initial calibration; clean injection port and front of GC column.
2. Base / neutral and acid extractable organic compounds
   - a. Extraction
     - 1) Adjust 100 ml sample to pH 2 or less, in a 125 ml separatory funnel.
     - 2) Extract with 10 ml methylene chloride.
     - 3) Shake for 2 minutes with proper venting and appropriate safety measures.
   - b. Analysis
     - 1) Inject 2 µl of extract
     - 2) Note that limits of detection vary depending on recovery and sensitivity of compound, 100 ppb-1 ppm.
   - c. Calibration standard solution
     - 1) Commercial (Supelco) solution containing the compounds of interest at appropriate concentrations
   - d. Quality control
     - 1) Inject calibration standard solution.
       - a) Once per site before sample analysis
       - b) Every 20 sample analyses
     - 2) Use spiked (field) sample to check extraction recovery.
       - a) Spiking solution of phenol, phenanthrene, 4-6-dinitro-2 methyl-phenol, hexachlorobenzene, and di-n-octyl-phthalate

**Exhibit 7A-1**
**(continued)**

b) Spike water sample at 1,000 µg/l

c) Spiked sample to check extraction recovery

(1) Every 20 sample extract analyses

(2) At least once per site

(3) Solvent blank

(a) After each calibration standard analysis

(b) After every 10 sample analyses

(4) Conduct corrective maintenance when calibration response decreases 20 percent from initial calibration; clean injection port and front of GC column.

## C. Soil / Sediment Sample Analysis

### 1. Pesticides / PCBs

a. Extraction

1) Place 1 g soil sample in glass scintillation vial of at least 20 ml volume with screw caps (Teflon or aluminum foil liner).

2) Add 2 g anhydrous sodium sulfate.

3) Mix well with spatula to free-flowing powder.

4) Add 10 ml hexane.

5) Shake for 2 minutes.

6) Allow solids to settle.

b. Analysis

1) 5 µl extract injected

2) Limits of detection 0.05 ppm for compounds such as lindane to 2 ppm for compounds such as Aroclor PCBs

c. Calibration standard solution

1) Pesticide solution of lindane, 0.005 ng/µl; aldrin, 0.01 ng/ml; and p-p'-DDT, 0.025 ng/µl

2) PCBs--Aroclor 1254, 0.15 ng/µl

d. Quality control

1) Calibration standard injected (both pesticides and PCBs)

a) Once per site before sample analysis

b) After every 10 sample analyses

2) Spiked (field) sample

a) Spiking solution--concentration in soil will be lindane, 50 ng/g; aldrin, 100 ng/g; and p-p'-DDT, 250 ng/g

b) Spiked sample every 20 samples

c) Once per site, minimum

3) Solvent blank injection

a) After each calibration standard solution injection

b) After every 10 samples extract

c) After any samples that exceed 20 ppm

4) Conduct corrective maintenance when calibration response decreases by 20 percent of initial calibration; clean injection port and front of GC column

### 2. Base / neutral and acid extractable compounds

a. Extraction

1) Place 1 g soil sample in glass scintillation vial of at least 20 ml volume with screw cap (Teflon or aluminum foil liner).

2) Add 2 g anhydrous sodium sulfate.

## Exhibit 7A-1
## (continued)

        3) Mix well with spatula to a free-flowing powder.
        4) Add 10 ml methylene chloride.
        5) Shake for 2 minutes.

        6) Allow solids to settle.

b. Analysis
    1) 2 µl extract injected
    2) Detection limits vary, 10 ppm-100 ppm

c. Calibration standard solution - commercial (Supelco) solution containing the compounds of interest at appropriate concentrations

d. Quality control
    1) Calibration standard injected
        a) Once per site prior to sample extract analysis
        b) After every 10 sample extract analyses
    2) Spiked (field) samples
        a) Spiking solution – concentration in soil will be 100 µg/g for each of the following compounds: phenol, phenanthrene, 4-6-dinitro-2-methyl phenol, hexachlorobenzene, and di-n-octylphthalate
        b) Spiked sample every 20 samples
        c) Spiked sample once per site, minimum
    3) Solvent blank injection
        a) After each calibration standard injection
        b) After every 10 sample extract analyses
        c) After any sample extracts that exceed 10,000 ppm
    4) Conduct corrective maintenance when calibration response decreases by 20 percent from initial calibration; clean injection port and front of GC column

## III. DELIVERABLES AND REPORTING - MOBILE LABORATORY ORGANICS ANALYSES

A. For each sample analyzed, a summary sheet containing the following information shall be provided:

1. Site name
2. Sample number
3. Date received
4. Date analyzed
5. Analyst
6. Number of peaks recorded on chromatogram (**Note:** For each sample chromatogram, peaks recorded will be numbered sequentially (#1, #2, #3, etc.) directly on the chromatogram)
7. Retention time of each peak
8. Relative concentration of each peak - compare sample chromatogram to calibration standard chromatogram; determine the closest eluting standard; and assume a response factor of 1.0. Other response factors may be assumed if indicated.

B. Copies of all analysts' logbooks, calibration logs, daily activity logs, and all chromatograms for calibration runs, blank injections, and samples will be received within 14 days of the receipt of the last sample from a particular site.

## Exhibit 7A-2
## TARGET COMPOUND LIST (TCL) ESTIMATED DETECTION LIMITS

| | | | Estimated Detection Limits*, ** | |
|---|---|---|---|---|
| | Volatiles$^{a,b}$ | CAS Number | Water µg/1 | Soil/Sediment µg/kg |
| 1. | Chloromethane | 74-87-3 | 10 | 10 |
| 2. | Bromomethane | 74-83-9 | 10 | 10 |
| 3. | Vinyl chloride | 75-01-4 | 10 | 10 |
| 4. | Chlorethane | 75-00-3 | 10 | 10 |
| 5. | Methylene chloride | 75-09-2 | 5 | 5 |
| 6. | Acetone | 67-64-1 | 10 | 10 |
| 7. | Carbon disulfide | 75-15-0 | 5 | 5 |
| 8. | 1, 1-Dichloroethene | 75-35-4 | 5 | 5 |
| 9. | 1, 1-Dichloroethane | 75-35-3 | 5 | 5 |
| 10. | Trans-1, 2-dichloroethene | 156-60-5 | 5 | 5 |
| 11. | Chloroform | 67-66-3 | 5 | 5 |
| 12. | 1,2-Dichloroethane | 107-06-2 | 5 | 5 |
| 13. | 2-Butanone | 78-93-3 | 10 | 10 |
| 14. | 1,1,1-Trichloroethane | 71-55-6 | 5 | 5 |
| 15. | Carbon tetrachloride | 56-23-5 | 5 | 5 |
| 16. | Vinyl acetate | 108-05-4 | 10 | 10 |
| 17. | Bromodichloromethane | 75-27-4 | 5 | 5 |
| 18. | 1,1,2,2-Tetrachloroethane | 79-34-5 | 5 | 5 |
| 19. | 1,2-Dichloropropane | 78-87-5 | 5 | 5 |
| 20. | Trans-1,2-dichloropropene | 10061-02-6 | 5 | 5 |
| 21. | Trichloroethene | 79-01-6 | 5 | 5 |
| 22. | Dibromochloromethane | 124-48-1 | 5 | 5 |
| 23. | 1,1,2-Trichloroethane | 79-00-5 | 5 | 5 |
| 24. | Benzene | 71-43-2 | 5 | 5 |
| 25. | Cis-1,3-dichloropropene | 10061-01-5 | 5 | 5 |
| 26. | 2-Chloroethyl vinyl ether | 110-75-8 | 10 | 10 |
| 27. | Bromoform | 75-25-2 | 5 | 5 |
| 28. | 2-Hexanone | 591-78-6 | 10 | 10 |
| 29. | 4-Methyl-2-pentanone | 108-10-1 | 10 | 10 |
| 30. | Tetrachloroethene | 127-18-4 | 5 | 5 |
| 31. | Toluene | 108-88-3 | 5 | 5 |
| 32. | Chlorobenzene | 108-90-7 | 5 | 5 |
| 33. | Ethyl benzene | 100-41-4 | 5 | 5 |
| 34. | Styrene | 100-42-5 | 5 | 5 |
| 35. | Total Xylenes | 100-42-5 | 5 | 5 |

## Exhibit 7A-2
## (continued)

| | Semi- Volatiles[a], [b] | CAS Number | Estimated Detection Limits*, ** Water µg/1 | Estimated Detection Limits*, ** Soil/Sediment µg/kg |
|---|---|---|---|---|
| 36. | N-nitrosodimethylamine | 62-75-9 | 10 | 330 |
| 37. | Phenol | 108-95-2 | 10 | 330 |
| 38. | Aniline | 62-53-3 | 10 | 330 |
| 39. | Bis (2-chloroethyl) ether | 111-44-4 | 10 | 330 |
| 40. | 2-Chlorophenol | 95-57-8 | 10 | 330 |
| 41. | 1, 3-Dichlorobenzene | 541-73-1 | 10 | 330 |
| 42. | 1,4-Dichlorobenzene | 106-46-7 | 10 | 330 |
| 43. | Benzyl alcohol | 100-51-6 | 10 | 330 |
| 44. | 1,2-Dichlorobenzene | 95-50-1 | 10 | 330 |
| 45. | 2-Methylphenol | 95-48-7 | 10 | 330 |
| 46. | Bis (2-chloroisopropyl) ether | 39638-32-9 | 10 | 330 |
| 47. | 4-Methylphenol | 106-44-5 | 10 | 330 |
| 48. | N-nitroso-dipropylamine | 621-64-7 | 10 | 330 |
| 49. | Hexachloroethane | 67-72-1 | 10 | 330 |
| 50. | Nitrobenzene | 98-95-3 | 10 | 330 |
| 51. | Isophorone | 78-59-1 | 10 | 330 |
| 52. | 2-Nitrophenol | 88-75-5 | 10 | 330 |
| 53. | 2,4-Dimethylphenol | 105-67-9 | 10 | 330 |
| 54. | Benzoic acid | 65-85-0 | 50 | 1600 |
| 55. | Bis (2-chloroethoxy) methane | 111-91-1 | 10 | 330 |
| 56. | 2,4-Dichlorophenol | 120-83-2 | 10 | 330 |
| 57. | 1,2,4-Trichlorobenzene | 120-82-1 | 10 | 330 |
| 58. | Naphthalene | 91-20-3 | 10 | 330 |
| 59. | 4-Chloroaniline | 106-47-8 | 10 | 330 |
| 60. | Hexachlorobutadiene | 87-68-3 | 10 | 330 |
| 61. | 4-Chloro-3-methylphenol (para-chloro-meta-cresol) | 59-50-7 | 10 | 330 |
| 62. | 2-Methylnaphthalene | 91-57-6 | 10 | 330 |
| 63. | Hexachlorocyclopentadiene | 77-47-4 | 10 | 330 |
| 64. | 2,4,6-Trichlorophenol | 88-06-2 | 10 | 330 |
| 65. | 2,4,5-Trichlorophenol | 95-95-4 | 50 | 1600 |
| 66. | 2-Chloronaphthalene | 91-58-7 | 10 | 330 |
| 67. | 2-Nitroaniline | 88-74-4 | 50 | 1600 |
| 68. | Dimethyl phthalate | 131-11-3 | 10 | 330 |
| 69. | Acenaphthylene | 208-96-8 | 10 | 330 |
| 70. | 3-Nitroaniline | 99-09-2 | 50 | 1600 |
| 71. | Acenaphthene | 83-32-9 | 10 | 330 |
| 72. | 2,4-Dinitrophenol | 51-28-5 | 50 | 1600 |
| 73. | 4-Nitrophenol | 100-02-7 | 50 | 1600 |
| 74. | Dibenzofuran | 132-64-9 | 10 | 330 |
| 75. | 2,4-Dinitrotoluene | 121-14-2 | 10 | 330 |

## Exhibit 7A-2
## (continued)

| | | | Estimated Detection Limits*, ** | |
|---|---|---|---|---|
| | Semi-Volatiles[c,d] | CAS Number | Water µg/1 | Soil/Sediment µg/kg |
| 76. | 2,6-Dinitrotoluene | 606-20-2 | 10 | 330 |
| 77. | Diethylphthalate | 84-66-2 | 10 | 330 |
| 78. | 4-Chlorophenyl phenyl ether | 7005-2-3 | 10 | 330 |
| 79. | Fluorene | 86-73-7 | 10 | 330 |
| 80. | 4-Nitroaniline | 100-01-6 | 50 | 1600 |
| 81. | 4,6-Dinitro-2-methylphenol | 534-52-1 | 50 | 1600 |
| 82. | N-Nitrosodiphenylamine | 86-30-6 | 10 | 330 |
| 83. | 4-Bromophenyl phenyl ether | 101-55-3 | 10 | 330 |
| 84. | Hexachlorobenzene | 118-74-1 | 10 | 330 |
| 85 | Pentachlorophenol | 87-86-5 | 50 | 1600 |
| 86. | Phenanthrene | 85-01-8 | 10 | 330 |
| 87. | Anthracene | 120-12-7 | 10 | 330 |
| 88. | Di-n-butylphthalate | 84-74-2 | 10 | 330 |
| 89. | Fluroanthene | 206-44-0 | 10 | 330 |
| 90. | Benzidine | 92-87-5 | 50 | 1600 |
| 91. | Pyrene | 129-00-0 | 10 | 330 |
| 92. | Butyl benzyl phthalate | 85-68-7 | 10 | 330 |
| 93. | 3, 3'-Dichlorobenzidine | 91-94-1 | 20 | 660 |
| 94. | Benzo (a) anthracene | 56-55-3 | 10 | 330 |
| 95. | Bis (2-ethylhexyl) phthalate | 117-81-7 | 10 | 330 |
| 96. | Chrysene | 218-01-9 | 10 | 330 |
| 97. | Di-n-octyl phthalate | 117-84-0 | 10 | 330 |
| 98. | Benzo (b) fluoranthene | 205-99-2 | 10 | 330 |
| 99. | Benzo (k) fluroanthene | 207-08-9 | 10 | 330 |
| 100. | Benzo (a) pyrene | 50-32-8 | 10 | 330 |
| | Pesticides[e,f] | | | |
| 101. | Ideno (1, 2, 3-cd) pyrene | 193-39-5 | 10 | 330 |
| 102. | Dibenz (a, h) anthracene | 53-70-3 | 10 | 330 |
| 103. | Benzo (g,h,i) perylene | 191-24-2 | 10 | 330 |
| 104. | Alpha-BHC | 319-84-6 | 0.05 | 2.0 |
| 105. | Beta-BHC | 319-85-7 | 0.05 | 2.0 |
| 106. | Delta-BHC | 319-86-8 | 0.05 | 2.0 |
| 107. | Gamma-BHC (lindane) | 58-89-9 | 0.05 | 2.0 |
| 108. | Heptachlor | 76-44-8 | 0.05 | 2.0 |
| 109. | Aldrin | 309-00-2 | 0.05 | 2.0 |
| 110. | Heptachlor epoxide | 1024-57-3 | 0.05 | 2.0 |

## Exhibit 7A-2
## (continued)

| | Pesticides[e],[f] | CAS Number | Estimated Detection Limits*, ** | |
|---|---|---|---|---|
| | | | Water µg/1 | Soil/Sediment µg/kg |
| 111. | Endosulfan I | 959-98-8 | 0.05 | 2.0 |
| 112. | Dieldrin | 60-57-1 | 0.10 | 4.0 |
| 113. | 4,4' -DDE | 72-55-9 | 0.10 | 4.0 |
| 114. | Endrin | 72-20-8 | 0.10 | 4.0 |
| 115. | Endosulfan II | 33213-65-9 | 0.10 | 4.0 |
| 116. | 4,4' -DDD | 72-54-8 | 0.10 | 20.0 |
| 117. | Endrin aldehyde | 7421-93-4 | 0.10 | 20.0 |
| 118. | Endosulfan sulfate | 1031-07-8 | 0.10 | 40.0 |
| 119. | 4,4' -DDT | 50-29-3 | 0.10 | 20.0 |
| 120. | Endrin ketone | 53494-70-5 | 0.10 | 20.0 |
| 121. | Methoxychlor | 72-43-5 | 0.5 | 20.0 |
| 122. | Chlordane | 57-74-9 | 0.5 | 20.0 |
| 123. | Toxaphene | 8001-35-2 | 1.0 | 20.0 |
| 124. | AROCLOR-1016 | 12674-11-2 | 0.5 | 40.0 |
| 125. | AROCLOR-1221 | 11104-28-2 | 0.5 | 40.0 |
| 126. | AROCLOR-1232 | 11141-16-5 | 0.5 | |
| 127. | AROCLOR-1242 | 53469-21-9 | 0.5 | |
| 128. | AROCLOR-1248 | 12672-29-6 | 0.5 | |
| 129. | AROCLOR-1254 | 11097-69-1 | 1.0 | |
| 130. | AROCLOR-1260 | 11096-82-5 | 1.0 | |

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[a] Medium Water Contract Required Detection Limits (CRDL) for Volatile Target Compound List (TCL) Compounds are 100 times the individual Low Water CRCL.

[b] Medium Soil/Sediment CRDL for Volatile TCL Componds are 100 times the individual Low Soil/Sediment CRDL.

[c] Medium Water CRDL for Semi-Volatile TCL Compounds are 100 times the individual Low Water CRDL.

[d] Medium Soil/Sediment CRDL for Semi-Volatile TCL Compounds are 60 times the individual low Soil/Sediment CRDL

[e] Medium Water CRDL for Pesticide TCL Compounds are 100 times the individual Low Water CRDL.

[f] Medium Soil/Sediment CRDL for Pesticide TCL compounds are 60 times the individual Low Soil/Sediment CRDL.

* Detection limits listed for soil/sediment are based on wet weight. The detection limits calculated by the laboratory for soil/sediment, calculated on dry weight basis as required by the contract, will be higher.

** Specific detection limits are highly matrix dependent. The detection limits listed herein are provided. for guidance and may not always be achievable.

## Exhibit 7A -3
## INORGANIC ANALYSIS PROTOCOLS

### PROTOCOLS FOR INORGANICS ANALYSIS – MOBILE LABORATORY AND FIXED-BASE LABORATORY

**Metals:** Approved EPA method for ICP, flame, flameless, or cold vapor atomic adsorption are used, provided that the required detection limits listed herein can be achieved. These methods are detailed in the CLP's *Scope of Work for Inorganic Analysis, Multi-Media, Multi-Concentration,* SOW No. 785, July 1985 (a new version is expected soon). However, perform digestion using a technique appropriate for the elements of concern. Perform analyses for the following elements:

aluminum
antimony
arsenic
barium
beryllium
cadmium
calcium
chromium
cobalt
copper
cyanide
iron
lead
magnesium
manganese
mercury
nickel
potassium
selenium
silver
sodium
thallium
vanadium
zinc

**Cyanide:** Use approved EPA method that meets the detection limits required herein, as specified in CLP SOW No. 785.

### DETECTION LIMITS

For inorganic analyses, use the required detection limits for soils. Limits should be no higher than 100 times the required limits for waters, which are listed below. (However, it is understood that occasional interferences may prevent these limits from being achieved in every case. Provide documentation stating the reason(s) if these limits are not achieved.)

**Element / Compound and Required Detection Limit in µg/l**

| | | | | | |
|---|---|---|---|---|---|
| aluminum | 200 | cobalt | 50 | nickel | 40 |
| antimony | 60 | copper | 25 | potassium | 5,000 |
| arsenic | 10 | cyanide | 10 | selenium | 5 |
| barium | 200 | iron | 100 | silver | 10 |
| beryllium | 5 | lead | 5 | sodium | 5,000 |
| cadmium | 5 | magnesium | 5,000 | thallium | 10 |
| calcium | 5,000 | manganese | 15 | vanadium | 50 |
| chromium | 10 | mercury | 0.2 | zinc | 20 |

## Exhibit 7A-3
(continued)

### GENERAL QUALITY CONTROL

- Perform one matrix spike and matrix spike duplicate on all fractions for each matrix (water or soil). Spike with as many compounds as are currently in a stock mix, and report all levels found.
- Perform one laboratory (method) blank on all fractions for each matrix (water or soil).
- Homogenize solids carefully.

### METALS ANALYSIS QUALITY CONTROL

- Whenever spike recoveries indicate that sample results for a particular metal may not be accurate, perform a standard addition on all samples (from one site) of the same matrix if the samples have positive results for this element. Use the control limits for spike recoveries as action levels for standard additions that must not exceed 60 to 140 percent. Report standard addition corrected results with a footnote that indicates this fact.
- Before running any samples and thereafter at least once per shift, run an instrument blank followed by calibration for all metals.
- Run a calibration check standard after every 10 samples are run on an instrument. Recalibrate, if necessary, based upon control limits that must not exceed 80 to 120 percent. If ICP is used, run a QC standard at least twice per shift to check interelement interference correction. Interferent concentrations should be approximately 100 to 1,000 times higher than analyte concentrations.
- When results for calibration check standards or ICAP interference check standards fall outside of control limits (which must not exceed 60 to 140 percent), reanalyze all preceding samples (since the last check analysis) having positive results for the affected parameters. Reanalysis should occur after the problem has been corrected.

### DELIVERABLES

- For each sample analyzed, provide a summary sheet containing the following information:
  - Site name
  - Sample number
  - Date received
  - Date analyzed
  - Analyst
- Report results for all samples, spikes, instrument, and method blanks. For each sample, list all compounds for which analyses were per formed with either the amount detected or the approximate detection limit next to each compound. Report results in mg/l or mg/kg. Do not perform subtraction of method or calibration blank values from sample results. Report quantitations to two significant figures.
- Report all matrix spike recoveries including amount added and recovered. If zero recoveries, check for a problem, and document the explanation in the results. Calculate and report the relative percentage of difference (difference divided by mean) for all matrix spike and matrix spike duplicate recoveries.
- Report the sample preparation weight / volume, the final analysis volume, and the injection volume for each sample and for each analytical fraction.
- Provide calibration check data for each sample run series. Report the true and measured concentrations of each analyte in the calibration checks.
- If ICP is used, provide results for all applicable interference check samples including true and measured concentrations of each analyte in the check sample.

**Exhibit 7A-3**
**(continued)**

- Report the type of analytical method used for each parameter analyzed, since different interferences occur with ICAP, Flame AA, and furnace methods.
- For each ICAP parameter, report the wavelength for measurement, together with a list of all known interfering elements and their approximate correction factors.

Receipt of results: Complete results and documentation (analysts' logbooks, calibration logs, daily activity logs, and all machine-generated documentation) must be received within 14 days of sample receipt for mobile laboratory analyses.

Verbal results for sample analyses will be provided upon request immediately following analysis; verbal results are simply an indication of the presence or absence of contaminants in samples.

Periodic analyses on EPA quality assurance check samples will be performed as established by data quality objectives and the QAPjP; results for these analyses will be reported in the same manner as any samples.

## Exhibit 7A-4
## OPERATING PROCEDURE FOR SRF ANALYSIS OF SOILS / TAILINGS WITH COLUMBIA SCIENTIFIC X-MET 840 ANALYZER

This procedure describes the use of the X-MET 840 X-ray fluorescence analyzer for analysis of heavy metals in solid samples.

### 1.0 EQUIPMENT

1. X-MET 840 XRF analyzer electronic unit.
2. HEPS sample probe, either Cm-244 or Am-241 radioisotope source, or both.
3. Distribution box (optional) for analysis requiring both probes.
4. Pure element standards, one for each element present within the samples to be analyzed.
5. Sample calibration standards.
6. Sample cups, polyethelene film, and scissors (included in unit storage box).
7. Automatic pulverizer, or mortar and pestle, for grinding samples to a powder.
8. Oven and aluminum pans for drying samples.
9. Acid-rinsed silica sand for cleaning grinding equipment.
10. Plastic sampling spoons.
11. Plastic vials (50 dram).

### 2.0 SAMPLE PREPARATION

This procedure describes the method of preparing both samples and calibration standards for analysis with the X-MET 840.

#### 2.1 Drying

In order to avoid analytical errors due to moisture content (a matrix effect) of all samples must be dried in the same manner.

2.1.1 Spread sample evenly in the aluminum pan. It is important that the sample in the pan be as homogeneous as possible and that all large chunks be broken up.

2.1.2 Place pan with sample in an oven and dry at 300°F for approximately 20 min., or until moisture is removed. Alternatively, samples may be dried in direct sunlight.

**Exhibit 7A-4**
**(continued)**

### 2.2 Subsampling

It is recommended that the entire sample be ground to avoid sampling error due to nonhomogeneity. However, if this is not possible, sampling error may be minimized by selection of a representative portion of the sample in the pan. With the use of a plastic spoon, remove one or more pie-shaped sections and place into the grinding apparatus.

### 2.3 Grinding

It is important that all samples be ground in the same manner. Analytical error due to differences in particle size can be substantial.

2.3.1 Samples should be ground with a portable hammer mill or, alternately, a mortar and pestle, until of equal consistency.

2.3.2 The grinding equipment must be cleaned (decontaminated) by grinding with silica sand. Liquid solvents should not be used.

### 2.4 Use of sample cups

2.4.1 Turn cup over and cover bottom with polyethelene film. Snap ring over film and onto bottom of cup. Cut cup free of film with scissors.

2.4.2 Trim excess film from edges of cup and check for holes or wrinkles. If the film is not completely smooth, or wrinkles cannot be removed, repeat the procedure.

2.4.3 Place sample in cup using a plastic spoon. Cups should be at least 3/4 filled with sample. Pack sample into cup until bottom (at film surface) is as smooth as possible. Brush away loose powder from outside edges of cup with a small brush to avoid contamination of the probe.

2.5 **Note:** Analysis with the X-MET requires only about 5 grams of sample. However, a minimum of approximately 40 grams is required for complete metals analysis by AAS or ICP techniques. Therefore, a minimum of 45 grams should be ground: 40 grams for verification and/or referee analyses and 5 grams retained for X-MET analyses. This is not critical if the entire sample is ground.

2.6 Ground powders should be stored in labeled plastic vials (50 dram).

## 3.0 PREPARATION FOR OPERATION

This procedure must be followed prior to both calibration (Section 4.0) and/or measurement (Section 5.0).

### 3.1 Power Supply

Connect the X-MET electronic unit to a suitable power source, either A.C. power, charged battery pack, or 12 volt battery. (**Note:** the unit will operate for approximately 8 hours on a fully charged battery pack).

### 3.2 Probe Connection

Connect probe cable to PROBE connector on bottom left of front panel. If more than one probe is to be used, they must be connected via the distribution box. (**Note:** Never connect / disconnect probe while the electronic unit is ON; this may damage the probe).

### 3.3 Switch ON

Turn the unit on by pressing the ON button. The display should then read: SELF TEST COMPLETED followed by the"" prompt and " _"cursor" indicator. The "" prompt indicates the ready (quiescent) state. (**Note:** Before switching the instrument OFF it should be returned to the quiescent state).

### 3.4 Electrical and Thermal Stabilization

Allow the unit to stabilize for approximately 30 min., prior to any measurements. Stabilization time is required to allow the X-MET to adjust to its surroundings. At least 1 min., of stabilization time should be allowed for each 1 deg F temperature change. (**Note:** When using 2 or 3 probes via the distribution box, electrical stabilization occurs simultaneously for all probes).

**Exhibit 7A-4**
**(continued)**

### 3.5 Gain Control

Each probe should be allowed at least 5 min., for gain control operation. Gain control takes place automatically when the unit is in the quiescent state ("'" prompt) and the probe shutter is closed (lid open and green light on).

3.5.1 If the display reads: UNINITIALIZED PROBE, then no initial value have been entered for gain control and an instrument calibration must be performed before proceeding further.

3.5.2 Gain control parameters may be checked and/or changed via the maintenance set of programs () refer to Section 9.0).

3.5.3 The unit should be left ON between measurements with probe shutter closed for continuous gain control operation.

3.5.4 When more than one probe is being used, each must be allowed separate gain control operation.

### 3.6 Update Normalization Factors

Due to continual decay of the radioactive source in the probe, it may be necessary to check and/or update the pure element normalization factors. This is not usually necessary unless a significant amount of time has elapsed between successive uses of the instrument.

3.6.1 Select approximately the same time as in the previous normalization. Key in the NOR command. The display should read: NORMALIZING SAMPLE? Enter the element symbol for which normalization is desired. The display should now reads: MEASURE. Place the corresponding pure element standard in position in the probe, open the shutter (close the lid) and measure (press START button).

3.6.2 If the relative deviations between old and new normalization factors are less than about 3%, or if the new measurements are statistically equal to each other, measurements can begin; otherwise, a new instrument calibration is required before proceeding.

## 4.0 CALIBRATION

The calibration procedure programs the X-MET 840 for the desired application. The elements to be analyzed are defined by setting up element channels (or windows) using the pure element standards. Concentrations of elements are established by measuring known calibration standards and calculating calibration coefficients using multiparameter regression analysis. There are eight separate calibration memories or "models". In each model, 1 to 10 element channels can be set up.

Figure 1 shows a diagram summarizing the main steps in the calibration procedure. Because of the complexities involved, only a brief description of the process is given here (refer to the operating manual for a more detailed discussion).

### 4.1 Instrument Calibration

Instrument calibration encompasses gain control initialization and stabilization, choice of elements, and pure element measurements. The choice of elements to measure depends on knowledge of their concentrations in the samples to be analyzed and their suspected degree of spectral interference. Once the appropriate pure elements have been selected, follow Sections 2.0 (Preparation for Operation) and 5.0 (Measurement). Pure element calibration is initiated through the PUR or CPU commands.

### 4.2 Sample Calibration

Sample calibration includes measurement of calibration standards (CAL command), input of calibration standard concentrations (ASY command), and calculation of calibration coefficients (MOD command). Calibration coefficients may also be calculated externally and entered via the PAR command. Follow Sections 2.0 (Preparation of Operation) and 5.0 (Measurement).

**Exhibit 7A-4**
**(continued)**

4.3 Number of Calibration Standards

The number of calibration standards depends on two factors: number of elements to be analyzed and number of interfering elements. Spectral overlap between elements is automatically corrected for through measurement of the appropriate pure element standards and selection of channel limits. Correction of matrix effects due to absorption or enhancement of fluorescent x-rays requires statistical evaluation. If a one-to-one correlation between element concentration and x-ray intensity (linear regression) is determined, the number of necessary calibration standards may be small. Matrix effects due to the presence of interfering elements, on the other hand, may require the use of multiple regression analysis, and the number of calibration standards necessary may increase (refer to Table 1).

## 5.0 MEASUREMENT

This section describes the measurement of either standards (calibration or pure element) or samples.

5.1 Select the appropriate model by pressing the MODEL function key, typing in the desired model (1-8), and pressing the CONT/YES editing key.

5.2 Select the appropriate measurement time by pressing the MTIME function key, typing in the desired time in seconds, and pressing the CONT/YES editing key. (**Note:** Measurement times may range between 1 and 32,767 seconds and it is not necessary that sample measurement times be the same as calibration measurement times.)

5.3 Place sample to be measured in the sample holder in the appropriate probe. Close the lid (green light should go out) and press START button. The screen should now indicate the remaining measurement time. At the end of measurement, an audible signal (three short tones) is given and the results displayed. Raise the probe lid and remove the sample.

5.4 If the sample is to be run again with another probe connected via the distribution box, turn the probe indicator switch to that probe and repeat steps 5.1 through 5.3.

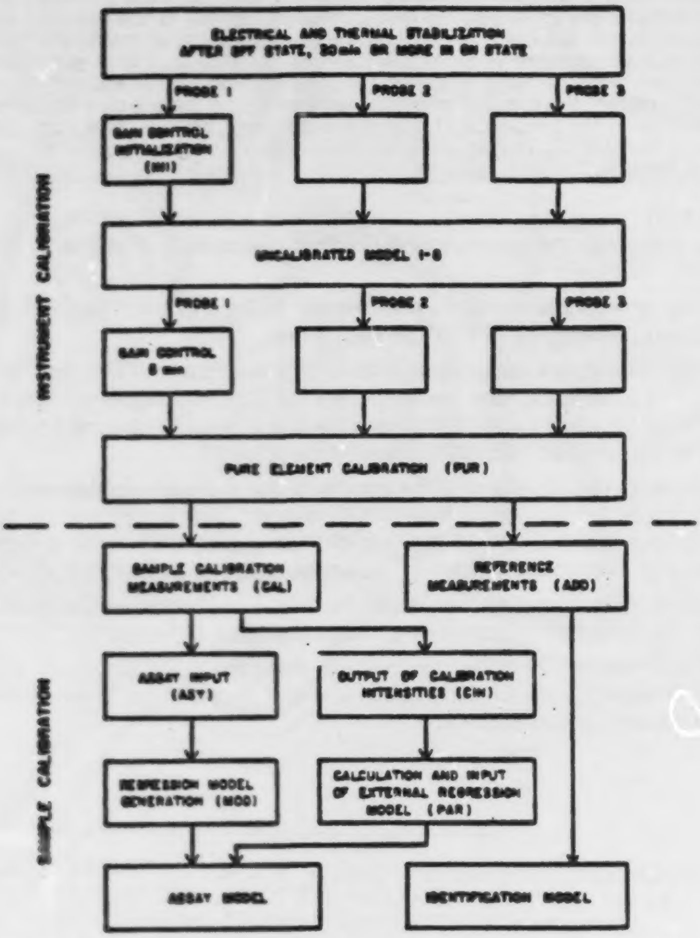
5.5 To re-display the results of the previous run, press the RECALC button. If calculations are desired for the previous run under a different model, first change to the desired model (see Section 5.1) and then press RECALC.

**TABLE 1**
**RECOMMENDED MINIMUM NUMBER OF CALIBRATION SAMPLES VERSUS NUMBER OF ELEMENTS TO BE ANALYZED AND NUMBER OF INTERFERING ELEMENT (INTENSITIES)**

| | Number of Elements | | | | | |
|---|---|---|---|---|---|---|
| Intensities | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 5 | 5 | 10 | 15 | 30 | 30 |
| 2 | 5 | 5 | 10 | 15 | 30 | 30 |
| 3 | 5 | 10 | 10 | 15 | 30 | 30 |
| 4 | 5 | 15 | 15 | 15 | 30 | 30 |
| 5 | 5 | 30 | 30 | 30 | 30 | 30 |
| 6 | 5 | 30 | 30 | 30 | 30 | 30 |

## Exhibit 7A-4
## (continued)

Figure 1 – Summary of calibration procedure


ELECTRICAL AND THERMAL STABILIZATION
AFTER OFF STATE, 30 min OR MORE IN ON STATE
PROBE 1
PROBE 2
PROBE 3
GAIN CONTROL INITIALIZATION (INI)
UNCALIBRATED MODEL 1-8
PROBE 1
PROBE 2
PROBE 3
GAIN CONTROL 5 min
PURE ELEMENT CALIBRATION (PUR)
SAMPLE CALIBRATION MEASUREMENTS (CAL)
REFERENCE MEASUREMENTS (ADD)
ASSAY INPUT (ASY)
OUTPUT OF CALIBRATION INTENSITIES (CIN)
REGRESSION MODEL GENERATION (MOD)
CALCULATION AND INPUT OF EXTERNAL REGRESSION MODEL (PAR)
ASSAY MODEL
IDENTIFICATION MODEL
INSTRUMENT CALIBRATION
SAMPLE CALIBRATION

## Exhibit 7A-4
## (continued)

## 6.0 QA/QC

### 6.1 Quality Control

Throughout the analysis, midpoint standards should be re-checked after an average of approximately five sample runs. Analyses are generally considered to be out of control when values obtained for the check standards are outside ±3 standard deviations of their "true" value. The instrument is then recalibrated and the previous samples rerun.

### 6.2 Instrumental Precision and Detection Limit

The standard deviation of counting statistics (STD command) can be considered a very close approximation of instrumental precision. True instrumental precision is obtained by repetitive measurements of a sample. As a general rule, the detection limit may be established as three times the instrumental precision. (**Note:** Instrumental precision can be increased and thus detection limit lowered by increasing the number of calibration standards and/or the measurement time).

### 6.3 Sample Splits

Sampling error can be determined by running sample duplicates, or splits. Both field duplicates and splits from the sample pan (if applicable) should be run an average of one every 20 samples. To test for grinding error due to powder non-homogeneity, powder splits should also be run at the rate of one per 20 samples.

## 7.0 FUNCTION KEYS

| Key | Description |
|---|---|
| START | Start measurement |
| MODEL | Select Model |
| MTIME | Select measurement time |
| RECALC | Recalculated assay in selected model |
| ON | Switch on |
| OFF | Switch off |

## 8.0 EDITING KEYS

| Key | Description |
|---|---|
| "<" | Delete keyboard entry |
| " " | Scroll backwards |
| SHIFT | Shift to upper case (if in lower case) or to lower case (if in upper case) |
| CONT/YES | Accept, continue or scroll forwards |
| END/NO | Reject, terminate or agree to negative question |

## 9.0 COMMANDS

| Key | Description |
|---|---|
| ADD | Add reference samples to identification library |
| ASY | Enter assays of calibration samples |
| CAL | Measure calibration samples |
| CIN | Output calibration sample intensities |
| CMS | Measure repeatedly (continuously) |
| CPU | Transfer or continue instrument calibration |
| DEL | Delete model |
| DTM | Display time and date |
| EMP | Enter maintenance programs (with PRM) |
| INI | Initialize gain control |
| INT | Output net count rates of channels |
| LIM | Examine and edit channel limits |
|  | Output normalization factors |
| LOC | Lock the keyboard |
| MOD | Regression modeling |

**Exhibit 7A-4**
**(continued)**

| | |
|---|---|
| NOR | Normalization |
| PAR | Enter and edit calibration coefficients |
| PUL | Output gross count rates of element channels |
| PUR | Instrument ("Pure Element") calibration |
| PRM | Instrument Calibration Parameters (with EMP) |
| REF | Referencee sample examination and editing |
| SPE | Output spectra |
| SPL | Plot spectra |
| STD | Output standard deviation (counting statistics) |
| STM | Set time and date |
| TCR | Output total count rate |
| UNL | Unlock keyboard |

## 10. REFERENCES

Columbia Scientific Industries Corp. 1985. Operating Instructions X-Met 840 Portable XRF Analyzer.

# SECTION 8

# EARTH SCIENCES

**Note:** Because the scope of this section is large, the section is organized by topics; the most pertinent topics, in order, are as follows:

| Section | Topic |
|---|---|
| 8.1 | Geologic Drilling |
| 8.1.6.1 | Drilling Methods |
| 8.1.6.1.1 | Hand Augers |
| 8.1.6.1.2 | Powered Augers |
| 8.1.6.1.3 | Hollow-Stem Augers |
| 8.1.6.1.4 | Solid-Stem Augers |
| 8.1.6.1.5 | Bucket Augers and Disk Augers |
| 8.1.6.1.6 | Cable Tools |
| 8.1.6.1.7 | Mud and Water Rotary Drilling |
| 8.1.6.1.8 | Air Rotary Method |
| 8.1.6.1.9 | Reverse Air-and Mud or Water Rotary |
| 8.1.6.1.10 | Drive and Wash |
| 8.1.6.2 | Sampling Techniques |
| 8.1.6.2.1 | Split-Spoon Samplers |
| 8.1.6.2.2 | Thin-Walled Tube Samplers |
| 8.1.6.2.3 | Cutting or Wash Samples |
| 8.1.6.3 | Decontamination and Waste Handling |
| 8.2 | Test Pits and Excavations |
| 8.3 | Geological Reconnaissance and Geological Logging |
| 8.3.5.1 | Geological Reconnaissance |
| 8.3.5.2 | Geological Logging |
| 8.3.5.2.2 | Methods - Soils |
| 8.3.5.2.3 | Soil Description |
| 8.3.5.2.4 | Rock Methods |
| 8.3.5.2.5 | Rock Classifications |
| 8.3.5.2.6 | Well Completion Diagrams |
| 8.4 | Geophysics |
| 8.4.2 | Geophysical Methods |
| 8.4.2.1 | Electromagnetics |
| 8.4.2.2 | Electrical Resistivity |
| 8.4.2.3 | Seismic Methods |
| 8.4.2.4 | Magnetics |
| 8.4.2.5 | Ground Penetrating Radar |
| 8.4.3 | Borehole Geophysics |
| 8.4.3.1.1 | Electrical |
| 8.4.3.1.2 | Nuclear |
| 8.4.3.1.3 | Mechanical |

Appendixes 8.4A to 8.4E contain detailed discussion of the theory of geophysical instruments.

8.5 Groundwater Monitoring
  8.5.6.1 Water Wells
  8.5.6.2 Lysimeters
  8.5.6.3 Piezometers and Tensiometers
  8.5.6.4 Groundwater Sampling Equipment
  8.5.6.5 Water-Level Measurement Devices
  8.5.6.6 Field Parameter Measurements
  8.5.6.7 Filtration
  8.5.6.8 Materials for Well Construction
  8.5.6.9 Groundwater Sampling Considerations

---

Each of the topics is organized into subsections on applications and limitations. These subsections follow the general compendium format.

## 8.1 GEOLOGIC DRILLING

### 8.1.1 Scope and Purpose

This subsection provides general guidance for the planning, method selection, and implementation of geologic drilling and subsurface soil sampling for field investigations of hazardous waste sites.

### 8.1.2 Definitions

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

**Soils**

"The collection of natural bodies on the earth's surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors. The lower limit is normally the lower limit of biological activity, which generally coincides with the common rooting of native perennial plants" (*Glossary of Geology*, 1972, p. 671). Typically, soils at a hazardous waste site are defined as the weathered material located above bedrock; thus, soil sampling can occur to depths of many feet.

### 8.1.3 Applicability

Although this subsection focuses on drilling for sampling purposes, it is important to recognize that borings are also required for in situ testing of subsurface materials and groundwater, and to allow installation of monitoring devices including wells.

Selection of the most appropriate method or combination of methods must be dictated by the special considerations imposed by multipurpose borings. For example, although the best apparent method for well installation at a particular site may be direct air rotary with driven casing, most air rotary equipment allows sampling only by cuttings. If, in this case, soil sampling is required, pilot (or separate) borings done with equipment capable of providing adequate undisturbed samples may be necessary. In addition, if drilling is to be conducted in an area of perched or multiple aquifer systems, auger techniques should not be used because of the possibility of cross contamination; borings must be advanced using multiple casing techniques that allow isolation of each aquifer encountered.

Examples of such optimization of techniques are too numerous to be thoroughly covered in this section, but the general applicability of various methods is discussed. Routine soil drilling and sampling techniques are discussed. Specialized techniques that may be applicable only under unusual conditions are not presented.

The planning, selection, and implementation of any drilling program requires careful consideration by qualified, experienced personnel. At a minimum, the following general steps are required:

- Review of existing site, area, and regional subsurface, geologic, and hydrogeologic information including physical and chemical characteristics
- Development of a site-specific health and safety program
- Definition of the purpose of the drilling and sampling, selection of drilling methods and general site layout, and preparation and execution of the drilling contract
- Field implementation and decontamination including continuous inspection by qualified, experienced personnel
- Reporting

Selection and implementation of soil drilling and sampling methods also require that specific considerations be given to the following issues, which are common to all drilling at or near hazardous waste sites:

- Prevention of contaminant spread
- Maintenance of sample integrity
- Minimization of disruption of existing conditions
- Minimization of long-term impacts

### 8.1.4 Responsibilities

The SM is responsible for determining that the soil drilling and sampling techniques being used are appropriate to the site conditions and drilling objectives.

### 8.1.5 Records and Inspection

All drilling and sampling activities should be continuously inspected by qualified, experienced personnel. Continuous inspection is essential to assure that the intent of the drilling program is being followed and to provide knowledgeable direction to the field crews when conditions dictate variance from the original plan.

Inspection personnel should prepare daily reports that include the following:

- Activity logs or field notebooks
- Boring logs
- Sample documentation

Reporting is essential to adequately document the unusual site conditions, the drilling and sampling quantities, and the personnel onsite for project control and to thoroughly document technical methods and results.

## 8.1.6 Procedures

The following methods should be considered for application at various sites. Exhibit 8.1-1 presents a summary of advantages, disadvantages, and depth limitations of various drilling techniques.

### 8.1.6.1 Drilling Procedures

#### 8.1.6.1.1 Hand Augers

**Description:** The most commonly used manually operated augers include the Iwan, ship, closed-spiral, and open-spiral augers. In operation, a hand auger is attached to the bottom of a length of pipe that has a crossarm at the top. The hole is drilled by turning this crossarm at the same time the operator presses the auger into the ground.

As the auger is advanced and becomes filled with soil, it is taken from the hole, and the soil is removed. Additional lengths of pipe are added as required. The Iwan, a post-hole type of auger, generally retains sample material better than the other hand-operated augers. Hand augers of the type mentioned are shown in Exhibit 8.1-2.

**Application:** In general, hand-operated augers are useful for sampling all types of soils except cohesionless materials below the water table and hard or cemented soils. The ship auger, with a helical flight on a solid stem, is best suited for use in cohesive materials. Spiral augers were developed for use in those cases in which helical and screw augers do not work well. The closed-spiral auger is used in dry clay and gravelly soils. The open-spiral auger is most useful in loosely consolidated deposits.

The Iwan auger is available in diameters ranging from 3 to 9 inches. The other types of augers are available in diameters ranging from approximately 2 to 3.5 inches.

Auger borings are used primarily in cases in which there is no need for undisturbed samples and in which the drilling will be done in soils where the borehole will stay open without casing or drilling mud, generally above the ground water table. The high mobility of the equipment makes the hand auger ideally suited for sites with impaired access.

## Exhibit 8.1-1
## DRILLING PROCEDURES SUMMARY

| Drilling Technique | Depth Limitation (ft) | Advantages | Disadvantages |
|---|---|---|---|
| Hand Auger | 30 | Mobility | Not useful in unconsolidated material below water table.<br>Not useful in cemented material.<br>Limited application in gravelly material.<br>Mixed samples. |
| Power-Assisted Hand Auger | 80 | Same as above. | Same as above. |
| Power Auger Hollow-Stem | 300 ± | Ease of soil sampling.<br>No fluids required. | Not good in caving formations or those containing boulders.<br>Not useful when undisturbed soil samples are required. |
| Solid-Stem | 100 | | |
| Bucket and Disk | | Holes up to 3 ft + in diameter.<br>Shallow holes above water table. | |
| Cable Tool | 1,000 + | Low drilling fluid requirements.<br>Good definition of water-bearing zones.<br>Good in caving, high-gravel content material.<br>Good formation in samples. | Slow.<br>Not good for small-diameter wells.<br>Must drive casing following bit. |
| Mud Rotary | 5,000 + | Good cutting samples.<br>Can leave hole open during drilling.<br>Rapid drilling. | Mud may plug permeable zones.<br>Not effective in boulder-rich sediments.<br>Not acceptable to EPA control of drilling fluids.<br>Lost circulation. |
| Air Rotary | 5,000 + | Fast in consolidated formations.<br>No drilling liquids introduced into well. | Small cuttings.<br>May be "watered out" in high-water zones.<br>Containment of drilling return difficult. |
| Reserve Air-and-Mud or Water Rotary | | Minimizes wellbore disturbance.<br>Better cuttings removal | Same limitations as mud rotary.<br>Best for holes > 12 inches. |
| Drive-and Wash | | | Limited to unconsolidated material.<br>Slow.<br>Large fluid volumes. |

**Limitations:** Borings drilled with augers have the disadvantage that the samples are mixed and that, in general, it is difficult if not impossible to locate precisely the changes in soil strata. Augering does not case off the upper portion of the hole. If the walls collapse or slough, representative samples may be difficult to obtain.

The exact depth to which any hole can be carried is a function of the types of soil in the profile, the type of auger being used, the amount of power available to turn the auger, and the location of the groundwater table. Gravel larger than 2 cm impairs the use of hand augers. Hand augers are typically used for shallow (2 to 8 feet) depths but may reach a maximum depth of 30 feet in unsaturated, unconsolidated material. These augers typically are not used for boring more than a few feet below the water table. Power assists have been added to hand auger systems to increase depth capability without substantially decreasing mobility.

### 8.1.6.1.2 Powered Augers

**Description:** A powered auger is motor-driven and is advanced by a helical worm with sections that can be screwed together. Three types of powered augers (which are discussed later) are hollow-stem, solid-stem, and bucket augers. The augers themselves are available in sizes ranging from 2 to 48 inches in diameter. The auger can be either hand held or rig mounted (Exhibit 8.1-3). The rig is self-sufficient and generally does not require additional lifting devices, although a simple hoist and tripod is useful in holes more than 10 feet deep.

Auger flights are available in several types depending on their intended use. These consist of single-flight earth augers, double-flight earth-rock augers, double-flight rock augers, and high-spiral augers (Exhibit 8.1-4). In operation, these augers are attached to a drilling rod, which is rotated and pressed downward to achieve penetration. The rod with the auger is advanced for the distance of the flight or until the flight has become filled with soil. The rod is then raised until the auger is clear of the hole, and the soil is thrown free from the cutter head. The hole is drilled by repeating this process until the required depth is reached. Two or four people can operate a powered auger.

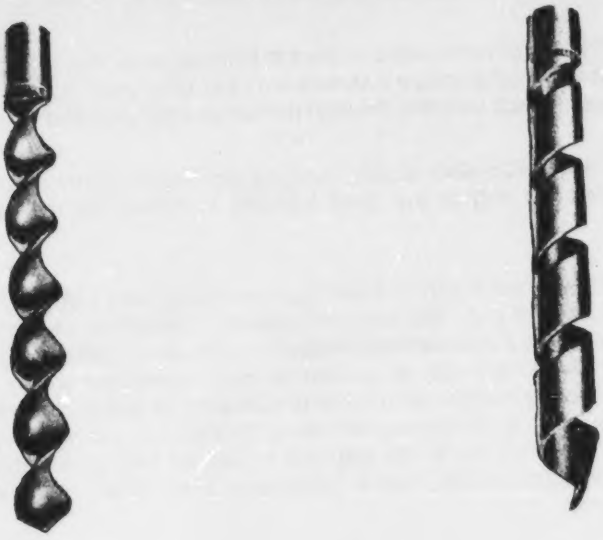
**Application:** The maximum depth of penetration that can be achieved with powered augers is limited by the geologic material, the depth to water, and the length of the Kelly rod that can be accommodated by the drilling rig used. In general, the depth is limited to between 100 and 200 feet. The advantage of auger boring over wash boring, percussion, and rotary drilling is that the cuttings brought to the surface (although disturbed) are generally suitable for positive identification of the soil material but not for precise soil content. Using powered augers also makes it easier to determine the groundwater level. Casing is not generally needed, except when drilling through noncohesive sand and gravel and sometimes when drilling below the water table. Drilling practice has shown that, where applicable, powered auger drilling is preferable to many other methods because the work progresses fast in drilling holes not deeper than 100 feet (when undisturbed samples are not required).

### 8.1.6.1.3 Hollow-stem Augers (Helical Augers)

**Description:** Hollow-stem augers (Exhibit 8.1-5) are a type of powered auger used primarily to advance the borehole when soil sampling is required. The hollow-stem auger consists of (1) a section of seamless steel tube with a spiral flight to which are attached a finger-type cutter head at the bottom and an adapter cap at the top, and (2) a center drill stem composed of drill rods to which are attached a center plug with a drag bit at the bottom and an adapter at the top. The adapters at the top of the drill stem and auger flight are designed to allow the auger to advance with the plug in place. As the hole is drilled, additional lengths of hollow-stem flights and center stem are added. The center stem and plug may be removed at any time during the drilling to permit disturbed, undisturbed, or core sampling below the bottom of the cutter head by using the hollow-stem flights as casing. This process also permits the use of augering in loose deposits below the water table. Where this technique is used in unconsolidated material

## Exhibit 8.1-2

## HAND AUGERS: (a) SHIP AUGER; (b) CLOSED-SPIRAL AUGER; (c) OPEN SPIRAL AUGER; (d) IWAN AUGER

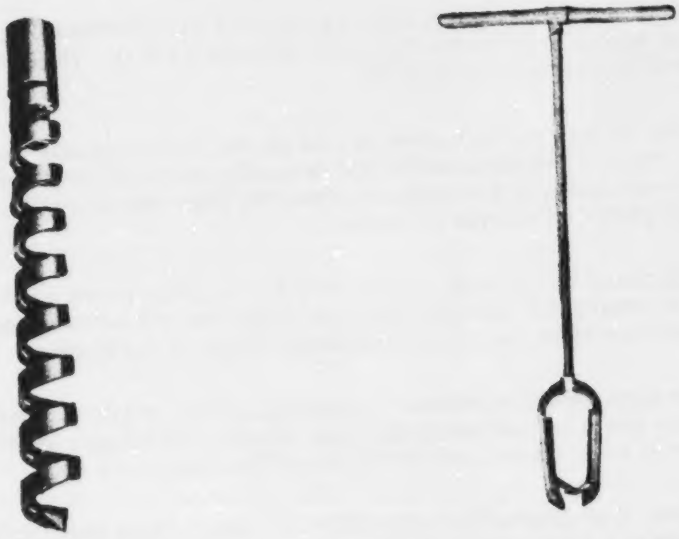


(a)

Ship Auger

(b)

Closed-Spiral Auger



(c)

Open-Spiral Auger

(d)

Iwan Auger

below the water table, fluids of known chemical quality may be used to control groundwater inflow. Undisturbed samples taken in this manner may be more useful than those taken from a cased hole, since the disturbance caused by advancing the auger is much less than that caused by driving the casing. Augers of this type are available with hollow stems having inside diameters from 2-3/4 to 6 inches.

**Application:** The use of hollow-stem augers is advantageous, because drilling fluids that need to be controlled and limited when advancing a borehole are used only under special circumstances. The augers also allow direct access for soil sampling through the hollow inner part of the auger stem.

The depths to which hollow-stem augers can bore are limited by the geologic formation and depth to groundwater. Hollow-stem augers are used primarily in formations that do not cave or have large boulders.

Upon reaching the desired depth, a small-diameter casing and screen can be set inside the hollow stem to produce a monitoring well. The augers are removed by section while the well screen and risers are held in place. Typically, one 5-foot section of auger is removed at a time. In incompotent formations, the borehole surrounding the screen may be allowed to cave around the screen, or a clean sand or gravel pack may be installed as the augers are withdrawn. Once the screen is properly covered (usually to 2 feet above the top of the screen), a clay (bentonite) seal is installed. As a final step, grout or other impermeable material is tremied in place on top of the clay seal to ground level as the remaining auger sections are removed. Careful installation of clay and/or grout seals is essential, especially in areas where multiple aquifers are encountered.

Allowing the formation to collapse around the well may damage the screen and/or risers. Depending on formation material, sand or gravel pack may provide a better performing well. Gravel packing may require a slightly larger hollow-stem auger but may be worth the effort.

### 8.1.6.1.4 Solid-stem Augers

**Description:** Solid-stem augers (Exhibit 8.1-6) are a type of powered auger that is advanced into the ground by the rotation and downward pressure of a rotary drill rig. These augers have interchangeable heads or bits for use in various types of soil.

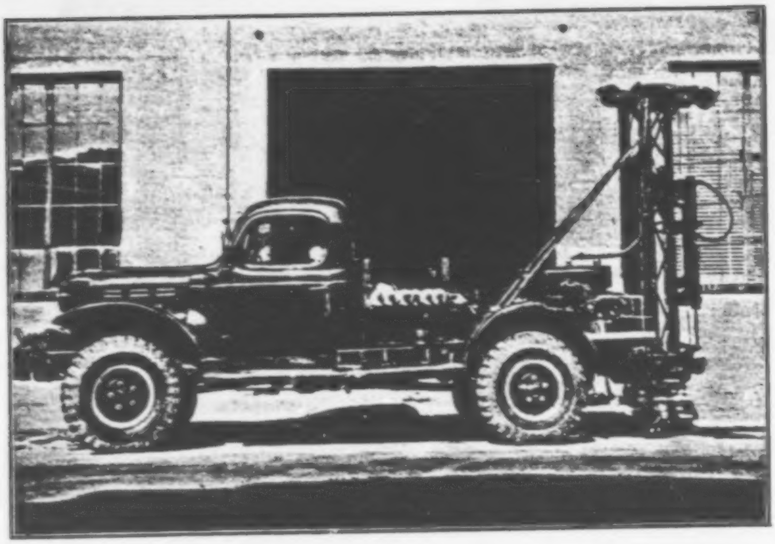
As the solid-stem auger is advanced into the ground, new auger sections are added. Auger borings may be advanced to a depth of about 100 feet, depending on the soil conditions encountered. Casing may be used to prevent caving in of unstable soil, especially below the water table, when the auger is removed for sampling or placement of a monitoring well.

The soil displaced by the auger is transported to the surface by the auger blade. This soil shows the general type of material through which the auger is passing, but definite determinations cannot be made about the depth from which the soil was excavated or about the soil structure.

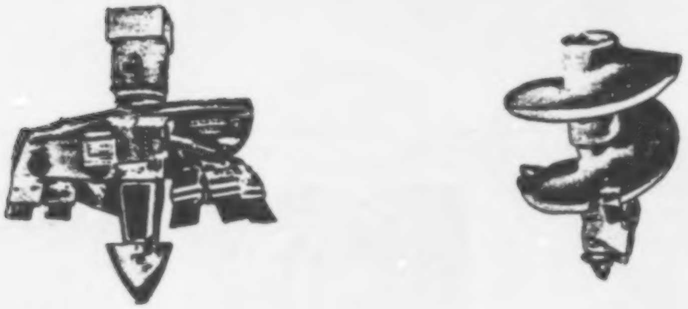
Solid-stem augers are most efficient in advancing a boring in moist, cohesionless soils with some apparent cohesion and in medium-soft tc stiff cohesive soils. These augers are not well suited for use in very hard or cemented soils, very soft soils, or saturated cohesionless soils.

**Application:** Borings advanced with solid-stem augers are not useful when it is necessary to obtain undisturbed samples of soil material or to determine the location of soil contacts. Under certain conditions, solid-stem auger borings are useful in providing holes for monitoring well installation. It should be noted that it is almost impossible to drill through a contaminated soil zone with a solid- stem continuous-flight auger without downward transport of contaminants.

## Exhibit 8.1-3
## RIG-MOUNTED POWERED AUGER



## Exhibit 8.1-4
## AUGERS: (a) SINGLE-FLIGHT EARTH AUGER; (b) DOUBLE-FLIGHT EARTH-ROCK AUGER; (c) DOUBLE-FLIGHT ROCK AUGER; (d) HIGH-SPIRAL AUGER.

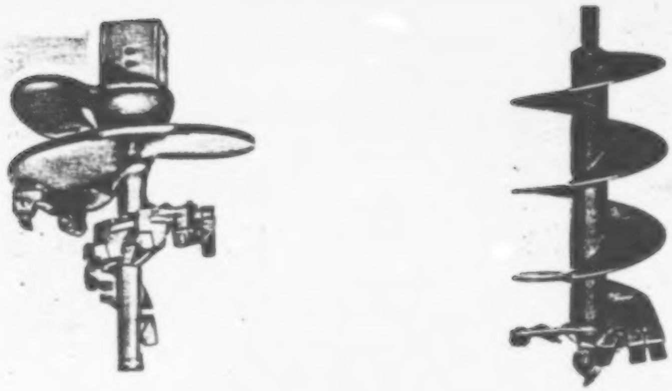


(a)

Single-Flight Earth Auger

(b)

Double-Flight Earth-Rock Auger



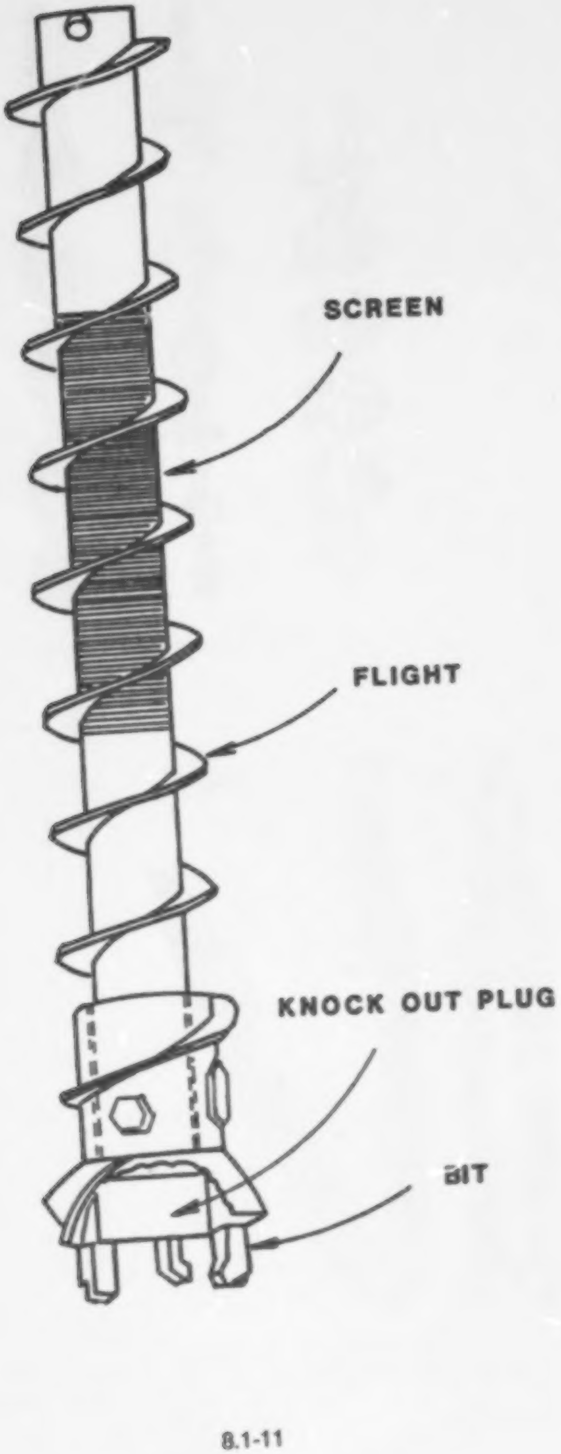
(c)

Double-Flight Rock Auger

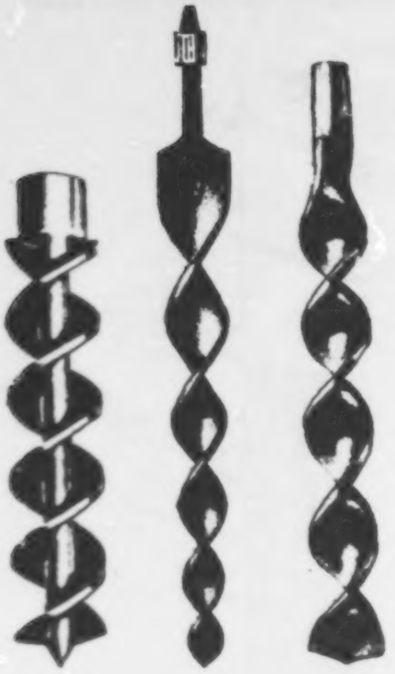
(d)

High-Spiral Auger

## Exhibit 8.1-5
## KECK-SCREENED, HOLLOW-STEM, CONTINUOUS-FLIGHT AUGER

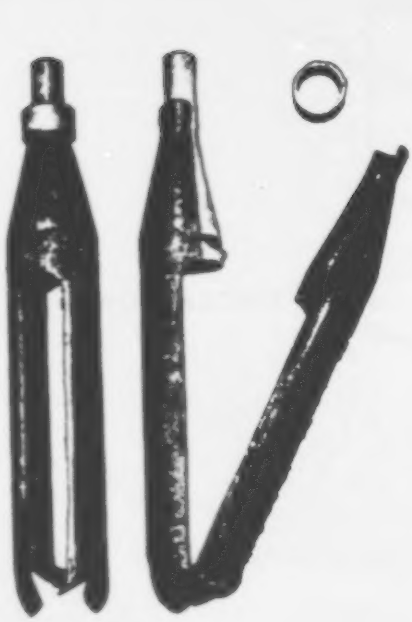

SCREEN
FLIGHT
KNOCK OUT PLUG
BIT

## Exhibit 8.1-6
## SOLID-STEM AUGERS

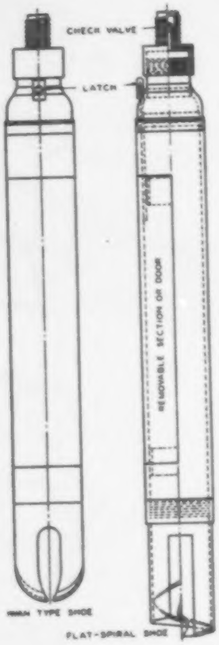


Large Helical or Worm-Type Augers

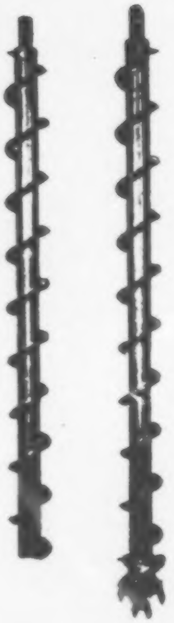
Spoon Auger



Vicksburg Hinged Auger :


CHECK VALVE
LATCH
REMOVABLE SECTION OF DOOR
WORM TYPE SHOE
FLAT-SPIRAL SHOE

Sprague & Henwood
Barrel Augers



Buda Continuous
Helical Augers

### 8.1.6.1.5 Bucket Augers and Disk Augers

**Description:** The bucket auger is a type of powered auger that consists of a cylindrical bucket 10 inches to 72 inches in diameter with teeth arranged at the bottom. The bucket is fastened to the end of a Kelly bar that is rotated and pushed downward. The bucket is then filled, brought to the surface, and emptied by tipping it over. Bucket holes more than 3 feet in diameter may be drilled using a special attachment. These wide holes permit visual inspection and direct sampling by a person lowered into the hole. Disk augers are similar to helical augers but are larger and are used to make larger holes. Helical and disk augers are shown in Exhibit 8.1-7. Large-diameter casing can be used to keep holes open in noncohesive material.

**Application:** These methods of augering are used if the boreholes are relatively shallow and above the water table. The methods are very rapid if boulders are not encountered.

### 8.1.6.1.6 Cable Tools

**Description:** A cable tool rig uses a heavy, solid-steel, chisel-type drill bit suspended on a steel cable that, when raised and dropped, chisels or pounds a hole through the soil and rock. Cable tool drilling is also commonly referred to as percussion drilling or churn drilling. Required equipment includes a drilling rig, a drill stem, percussion bits, and a bailer. Casing is needed when advancing a hole through soft, caving materials. Cable tool drilling equipment is shown in Exhibit 8.1-8.

**Application:** Cable tool rigs can operate satisfactorily in all formations, but they are best suited for large, caving, gravel-type formations with cobbles or boulders or for formations with large cavities above the water table. The use of cable tool rigs for small diameter (2-inch) wells is not recommended.

Information regarding water-bearing zones can be easily obtained during cable tool drilling. Relative permeabilities and some water quality data can be obtained from different zones penetrated if a skilled operator is available. Formation samples can be excellent when a skilled driller uses a sand pump bailer.

In hazardous waste applications, contaminated materials can be closely controlled through periodic bailing and through containment of suspended cuttings. Some water is required to replace water removed by bailing in unsaturated zones, but the water requirements for this method of drilling are generally low.

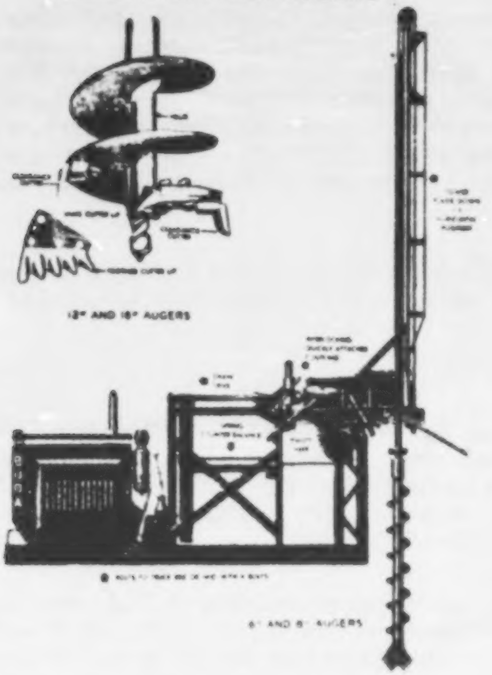
**Limitations:** Cable tool drilling is slow compared with rotary drilling. The necessity of driving the casing along with drilling in unconsolidated formations requires that the casing be pulled back to expose selected water-bearing zones. This process complicates the well completion process and often increases cost. Relatively large-diameter (at least 4 inches) casing is required, which increases the costs when compared with rotary-drilled wells with plastic casing. The casing, which has a sharp, hardened casing shoe on the bottom, must be driven into the hole. The shoe cuts a slightly larger hole than does the drill bit, and it can not be relied on to form a seal when overlying water-bearing zones are encountered.

With some types of cable tool drilling equipment, it may be difficult to reach some sites that are steep or marshy.

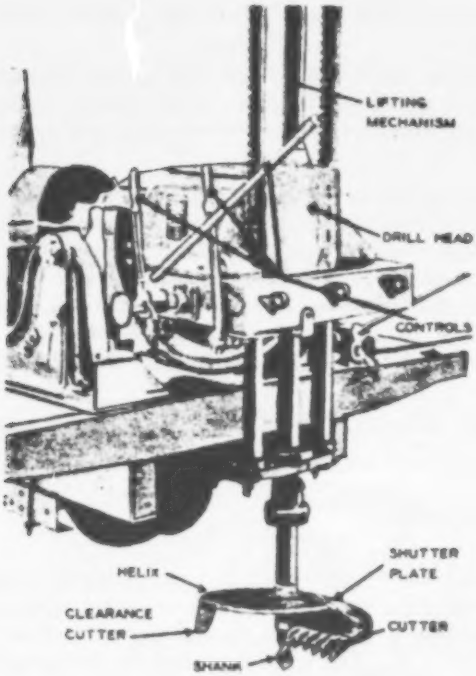
### 8.1.6.1.7 Mud and Water Rotary Drilling

**Description:** In rotary drilling, the borehole is advanced by rapid rotation of the drilling bit, which cuts, chips, and grinds the material at the bottom of the hole into small particles. The cuttings are removed by pumping water or drilling fluid from a sump down through the drill rods and bit and up the annulus between the borehole wall and the drill rods. This water flows first into a settling pit and ultimately back to the

## Exhibit 8.1-7
## HELICAL AND DISK AUGERS


12" AND 16" AUGERS
6" AND 8" AUGERS

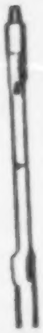
Buda Earth Drill with Continuous Helical Augers


LIFTING
MECHANISM
DRILL HEAD
CONTROLS
HELIX
SHUTTER
PLATE
CLEARANCE
CUTTER
CUTTER
SHANK

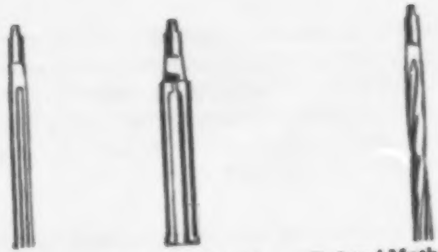
Buda Earth Drill with Disk Auger

## Exhibit 8.1-8
## CABLE TOOL (PERCUSSION) DRILLING EQUIPMENT

Drilling Rig



Drill Stem

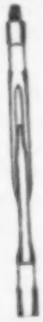


Regular

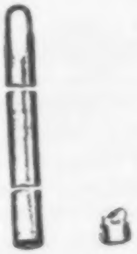
Mother Hubbard

Twisted Mother Hubbard

Chopping Bits



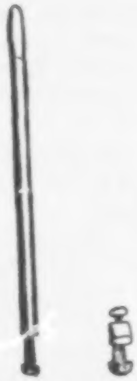
Drill Jar



Bailer

Valve

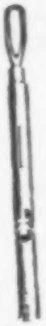
Flat Valve Bailer



Bailer

Valve

Dart Valve Bailer



Rod Plunger Type
Sand Pump
with Regular Bottom

main pit for recirculation. Water alone may be used when the depth is small and the soil is stable. Drilling mud is sometimes preferred, since the required flow is smaller and the mud serves to stabilize the hole; however, the mud may clog permeable soil units. A sample should be collected of any material introduced into the well (water, drilling mud, additives, etc.). The sample should be retained for future analysis if any question of contamination arises. A section of casing is used to start the hole, but the remaining part of exploratory boreholes advanced by rotary drilling is usually uncased except in soft soils.

When rotary drilling is used for exploratory borings, items such as motors, rotary driving mechanisms, winches, and pumps, are generally assembled as a unit, with a folding mast mounted on a truck or tractor. The unit also may be mounted on intermediate skids so that it can be placed on a raft or moved into places inaccessible to motor vehicles. A diagrammatic sketch of such a drilling rig is shown in Exhibit 8.1-9. Skid mounted drilling machines can also be used for rotary drilling.

Many types of rotary drilling bits are used, depending on the character of the material to be penetrated. Fishtail bits and two-bladed bits are used in relatively soft soils and three- to four-bladed bits in firmer soils and soft rock. The cutting edges are surfaced with tungsten carbide alloys or are formed by special hard-metal inserts. The bits used in rock have several rollers with hard-surfaced teeth. The two-cone bits are used in soft or broken formations, but the tri-cone and roller bits provide smoother operation and are more efficient in harder rocks. The number of rollers and the number and shape of the teeth are varied in accordance with the character of the rock. Relatively few and large teeth are used in soft rock, and the teeth are interfitting so that the bit will be self-cleaning. The teeth in all bits are flushed by drilling fluid flowing out of vents in the base of the bit.

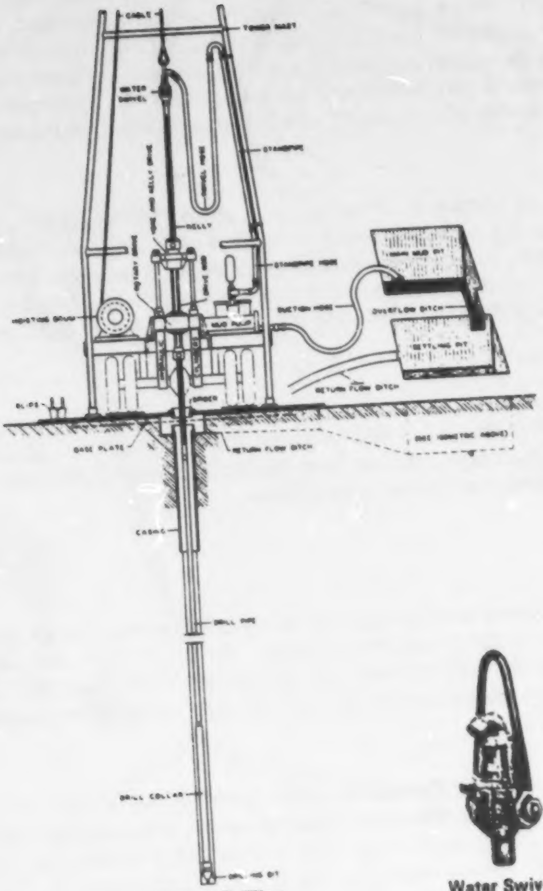
Boreholes produced by rotary drilling may be cased to provide stability. The drill rod and bit can be removed from the borehole, and a sampler can be lowered through the casing to remove soil from the bottom of the boring.

Uncased boreholes are often filled with water to stabilize the hole and to remove material ground up by the boring tools. Water will exert a stabilizing effect on the parts of the hole that extend below groundwater level; however, above the water table, the water may result in a loss of soil strength and a collapse of the hole. Water alone generally prevent neither caving of borings in soft or cohesionless soils nor a gradual squeezing-in of a borehole in plastic soils. Uncased boreholes filled with water are generally used in rock and are often used in stiff, cohesive soils.

An uncased borehole can often be stabilized by filling it with a properly proportioned drilling fluid or "mud," which, when circulated, also serves to remove ground-up material from the bottom of the hole. A satisfactory drilling fluid can occasionally be obtained by mixing locally available fat clays with water, but it is usually advantageous and often necessary to add commercially prepared drilling mud addatives. When suitable native clays are not available, the drilling fluid is prepared with commercial products alone. These mud-forming products consist of highly colloidal, gel-forming, thixotropic clays—primarily bentonite—with various chemicals added to control dispersion, thixotropy, viscosity, and gel strength. A sample of the drilling fluid should be analyzed to eliminate the possibility of introducing contamination into the borehole.

The stabilizing effect of the drilling fluid is caused in part by its higher specific gravity (in comparison with water alone) and in part by the formation of a relatively impervious lining or "mudcake" on the side walls of the borehole. This lining prevents sloughing of cohesionless soils and decreases the rate of swelling of cohesive materials. The drilling fluid also facilitates removal of cuttings from the hole. The required velocities and volume of circulation are smaller than for water alone, and the problem of uncontrolled erosion at the bottom of the hole is decreased. Furthermore, the drilling fluid is thixotropic; that is, it stiffens and forms a gel when agitation is stopped, and it can be liquified again by resuming the agitation. Drilling mud is, therefore, better able than water to keep the cuttings in suspension during the time required for withdrawal and reinsertion of boring and sampling tools. It also reduces abrasion and retards corrosion of these tools.

## Exhibit 8.1-9
## MUD AND WATER ROTARY DRILLING


CABLE
TOWER MAST
WATER SWIVEL
STANDPIPE
KELLY
STANDPIPE HOSE
SUCTION HOSE
OVERFLOW DITCH
HOISTING DRUM
MUD PUMP
SETTLING PIT
RETURN FLOW DITCH
SLIPS
BASE PLATE
RETURN FLOW DITCH
CASING
DRILL PIPE
DRILL COLLAR
DRILLING BIT

Rotary Drilling

Truck-Mounted Rotary Drilling Rig

Water Swivel

Hoisting Plug

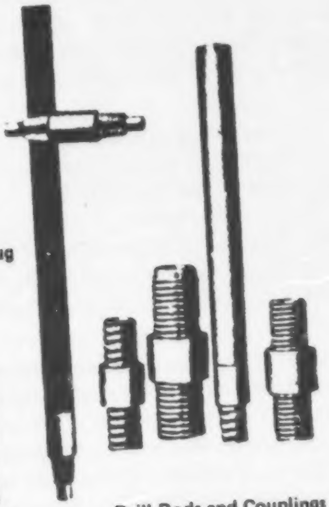
Two-Blade Bit

Three-Blade Bit

Four-Blade Bit

BLADED BITS

Fishtail Bit



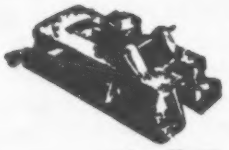
Drill Rods and Couplings

Two-Cone Bit

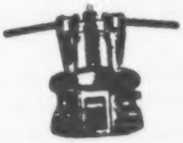
Tri-Cone Bit

ROCK BITS

Roller Bit



Safety Clamp



Spider and Slips

**Application:** Rotary drilling is best suited for borings with a diameter of not less than 4 inches; a diameter of 6 to 8 inches is generally preferred when the method is used for exploratory boring. In most soils and rocks, the rate of progress is greater than that of other methods. However, rotary drilling is not well suited for use in deposits containing very coarse gravel, numerous stones and boulders, or chert nodules; in badly fissured or cavernous rock; or in very porous deposits with a strong groundwater flow, since an excessive amount of drilling fluid may be lost by seepage in such formations. Judicious selection of drilling mud additives and lost circulation material can ameliorate fluid loss problems. This method has a rapid drilling rate and generally can avoid placement of a casing by creating a mud lining on the wall of the well.

Major disadvantages of rotary drilling are as follows: (1) If not properly used, drilling fluids may introduce potential contaminants into the borehole; (2) a large amount of water needs to be controlled after use; and (3) the problem of lost circulation exists in highly permeable or cavernous geologic formations. The "filter cake" produced when drilling mud is used may reduce the permeability in water-bearing zones. Proper completion and well development can significantly lessen the adverse effect of filter cake and mud invasion into a formation.

When using the rotary drilling method for the installation of monitoring wells, care must be exercised to prevent recirculation of potentially contaminated drilling fluids into uncontaminated formations. In addition, during well development, drilling fluids must be thoroughly flushed from the borehole and the invaded zone to ascertain that samples collected are representative of true formation fluids.

### 8.1.6.1.8 Air Rotary Method

**Description:** Air rotary rigs operate in the same manner as mud rotary drills, except the air is circulated down the drill pipe and returns with the cuttings up the annulus. Air rotary rigs are available throughout much of the United States and are well suited for many drilling applications. A variation of the air rotary method is the air hammer method, which uses a pneumatic or percussion hammer that pulverizes rock and uses air to return cuttings to the surface.

Air rotary rigs operate best in hard rock formations. Formation water is blown out of the hole along with the cuttings, so it is possible to determine when the first water-bearing zone is encountered. After filtering water blown from the hole, collection and field analysis may provide preliminary information regarding changes in water quality for some parameters. Where significant water inflow is encountered, foaming agents may be added to enhance the ability of the air stream to remove cuttings from the wellbore. Formation sampling ranges from excellent in hard, dry formations to nonexistent when circulation is lost in cavernous limestones and other formations with cavities.

Casing is required to keep the borehole open when drilling in soft, caving formations below the water table. When more than one water-bearing zone is encountered and where the hydrostatic pressures are different, flow between zones will occur between the time the drilling is done and the time the hole can be properly cased and one zone grouted off. Multiple casing strings can be used to rectify this problem, if necessary. Synthetic drilling aids are not usually used in air rotary drilling. If the air is filtered to capture compressor lubricants, contamination can be minimized more effectively than with other methods. In badly contaminated subsurface situations, air rotary drilling must be used carefully to minimize the exposure of drilling personnel to potentially hazardous materials.

**Application:** Air rotary methods are conducive to drilling in hard rock and other consolidated formations where a mud or water lining is unnecessary to support the walls against caving. An important advantage of using the air rotary method is that contamination of the water zone is not a factor since no drilling fluid is used.

### 8.1.6.1.9 Reverse Air-and-Mud or Water Rotary

**Description:** The difference between the straight rotary drilling method and the reverse rotary circulation method lies in the circulation of the drilling fluid used to remove the cuttings and in the equipment used. In the reverse rotary method, as the rods are rotated the drilling fluid is introduced under gravity into the annular space between the drill rods and the walls of the hole. The fluid, along with cuttings from the bottom of the hole, returns to the surface through hollow drill rods. The return flow is accomplished by (1) application of a head at the top of the annulus relative to the discharge end of the drill rods, (2) application of suction on the drill rods, and (3) introduction into the drill rods of a supply of air that mixes with the slurry and causes it to be removed by air lift.

**Application:** This method has two advantages. It minimizes disturbance to the walls of the hole because of the higher head in the hole and more outward seepage pressure on the hole walls. It also provides more rapid and efficient removal of cuttings from the hole, since the area of the drill rods is smaller than that of the annulus, thereby giving higher upward velocity. Reverse rotary drilling is best suited to holes 12 inches and larger in diameter, but it has the same limitations as the mud and water rotary system.

### 8.1.6.1.10 Drive and Wash

**Description:** The drive-and-wash method is similar to cable tool drilling and is often used in EPA Region I states. In this method of drilling, the casing is driven by a weight or hammer into the unconsolidated material. Soil entering the casing is washed out by circulating drilling fluid (water), and the casing is advanced again. A water rotary wash may also be used to clean the inside of the casing.

**Application:** Drive and wash is limited to unconsolidated materials. The casing also acts as a temporary seal to prevent cross-contamination of aquifers. Although faster than cable tool drilling, drive and wash is not a very rapid method. If the wash water is not recycled, large quantities of fluids may require collection and disposal.

### 8.1.6.2 Sampling Techniques

The purpose of soil sampling is to obtain a portion of soil (disturbed or undisturbed) that is representative of the horizon sampled for chemical analysis, geotechnical analysis, and geomorphological classification. The volume of each sample is about 1 pint. Samples are usually taken at intervals approved by the geologist or field engineer and at each change in formation or material type. Where sampling difficulties are encountered or a larger volume of material is needed, a larger diameter split-spoon sampler, a Shelby tube, a pitcher-type sampler, or a piston-type sampler might be required. Continuous coring may be desirable when it is necessary to establish the presence and distribution of permeable layers and to establish stratigraphic control.

In areas where contamination is possible, soil samples are usually screened for contamination by the use of various monitoring instruments (see Section 15). Any positive readings or visual evidence of contamination will necessitate treating the sample as a hazardous material and using appropriate packaging, labeling, and shipping techniques, as well as personal protection for the drillers and samplers. This level of protection should be determined before the start of drilling.

Standard penetration tests should be conducted in accordance with American Society for Testing and Materials (ASTM) D1586, with the interval tested varying from continuous sampling to 5-foot intervals. Where rock samples are required, N-series split inner tube core barrels are usually used. Air is the preferred drilling fluid. Techniques for obtaining and handling disturbed or undisturbed samples are described in this subsection.

### 8.1.6.2.1 Split-Spoon Samplers

The split-spoon sampler is a thick-walled, steel tube that is split lengthwise. A cutting shoe is attached to the lower end; the upper end contains a check valve and is connected to the drill rods. When a boring is advanced to the point that a sample is to be taken, drill tools are removed and the sampler is lowered into the hole on the bottom of the drill rods.

The sampler is driven 18 inches into the ground in accordance with a standard penetration test (ASTM D1586). The effort taken to drive the sampler the last 12 inches is recorded at 6-inch intervals, and the sampler is removed from the boring. The density of the sampled material is obtained by counting the blows per foot as the split-spoon sampler is driven by a 140-lb hammer falling 30 inches.

The standard-size split-spoon sampler has an inside diameter (ID) of 1.38 to 1.5 inches. When soil samples are taken for chemical analysis, it may be desirable to use a 2 or 2.5 ID sampler, which provides a larger volume of material but can not be used to calculate aquifer properties by using the stated ASTM test method.

Samples to be chemically analyzed are placed in the appropriately sized decontaminated jar and labeled with EPA serialized sample tags. Samples are kept out of direct sun light and stored at about 4C until they are shipped to the laboratory. The split-spoon sampler is decontaminated between samples. In some instances, separate, previously decontaminated split-spoon samplers may be required for each sample taken.

When taking samples for geotechnical analyses, the disturbed soil samples removed from the sampler are placed in a sealable glass jar and labeled to indicate the project name and number, boring number, date, depths at top and bottom of sample interval, recovery, number of sample, number of blows for each 6 inches (15 centimeters) of penetration, date of sampling, and any other information required by the field engineer or geologist. This information is placed on a gummed printed label that can be affixed to the jar. In addition, the jar lid is marked with the project number, boring number, number of sample, and depths at the top and bottom of the sample interval.

Jar samples are placed in containers, such as cardboard boxes, with dividers to prevent movement of the jars. To aid in retrieving samples, only one boring is generally placed in a box. The boxes are labeled on the top and four sides to show the project number and name, the identification of samples contained in the box, and the depth from which the samples were taken.

Samples are taken in 6-inch increments and are placed in jars or, where lenses or layers are evident, the material types should be separated into different jars. All samples recovered, except for slough or cuttings, should be saved until analysis is completed. They should then be properly disposed of. Section 5 of this compendium describes disposal of samples. Each 6-inch increment of a sample should be assigned a letter suffix, beginning with "A" at the bottom of the sample. If only 6 inches of a sample are recovered, this would be given the suffix "A."

If the jar samples are to be temporarily stored onsite, they should be protected from weather, especially heat and freezing temperatures. Evidence tape or custody seals should be placed across the jar lids. For commercial shipment, the boxes are marked "KEEP FROM HEAT AND FREEZING" and are labeled with the appropriate Department of Transportation (DOT) labels. The reader should refer to Section 5 of this compendium.

### 8.1.6.2.2 Thin-Walled Tube Samplers

Thin-walled samplers, such as a Shelby tube, are used to take relatively undisturbed samples of soil from borings. The samplers are constructed of cold drawn steel tubing about 1 mm thick (for tubes 2 inches in diameter) or 3 mm thick (for tubes 5 inches in diameter). The lower end is bent to form a tapered cutting edge. The upper end is fastened to a check valve to help hold the sample in the tube when the tube is being withdrawn from the ground. Thin-walled tube samples are obtained by any one of several methods including pushed-tube, Pitcher sampler, Denison sampler, and piston sampler methods. Choosing the most appropriate method requires that field personnel use their own judgment. Since the purpose of thin-walled tube sampling is to obtain the highest quality undisturbed samples possible, special care should be taken in all sampling, handling, packaging, and shipping of these samples.

In obtaining pushed-tube samples, the tube is advanced by hydraulically pushing in one continuous movement with the drill rig. The maximum hydraulic pressure is recorded. At the end of the designated push interval and before lifting the sample, the tube is twisted to break the bottom of the sample.

Upon recovery of a thin-walled tube, the actual length of sample is measured and recorded (excluding slough or cuttings). At least 1/2 inch of soil is cleaned from each end of the tube, and the ends of the soil sample are squared off. Usually the top of the sample will contain cuttings or slough. These must be removed before sealing. The soil that has been cleaned from the tube can be used for a visual classification of the sample. The resulting space at each end of the tube is filled with melted sealing material, such as approved wax, or with expandable packers. Previously decontaminated Teflon or stainless steel plugs are also used. After this initial sealing, a dry filler such as cuttings, sand, or paper can be placed in the remaining void areas, and sealing is again conducted. This filler prevents the sample from breaking the initial end seals during handling and shipment. The ends of the tube are then closed with tight-fitting metal or plastic caps, and the seam between the cap and tube is wrapped with tape. Finally, the ends are dipped in hot wax, completely covering the tape to ensure sealing.

The sample container and the top cap are labeled by writing on them with an indelible marker or by affixing a label. If possible, all labeling should be located in the top 1 foot of the tube. The information on the tube includes the project number, project name, date of sampling, boring number, sample number, zone of sampling, and any other information the field engineer or geologist feels is pertinent. In addition, the tube is marked TOP and BOTTOM so that the orientation of the soil sample is known.

As much as possible, the tubes should be carried by hand to the soils laboratory in an upright vertical position to maintain the in situ orientation and to minimize sample dis-aggregation. If the tubes are being transported by air plane, they should be carried, if possible, on the plane and not checked as baggage. (**NOTE:** Soil samples that yield positive readings during screening with an HNU or organic vapor analyzer (OVA), that show visual evidence of contamination, or that can reasonably be assumed to be contaminated should never be carried on a passenger aircraft. The reader should refer to Section 5 of this compendium for the proper packaging, labeling, and shipping of hazardous samples.) If the tubes are to be transported by truck or automobile, they should be carefully padded and wedged in place to prevent movement and minimize vibration. If tubes must be shipped as freight, they should be packed in secure wooden boxes with dividers built in to prevent movement of the tubes, or the boxes should be tightly filled with packing material such as wood chips to prevent movement. The boxes should be marked "FRAGILE" and "KEEP FROM HEAT AND FREEZING" and labeled according to the type of hazard presented by the assumed contamination. All packaging of tubes should be supervised by the field engineer or geologist.

Finally, if field engineers or geologists think the tubes have been disturbed in shipment, they should notify the Project Manager and soils laboratory coordinator in writing.

In addition to geotechnical testing, such as permeability testing, thin-walled samples may be extruded in the laboratory and used for chemical analysis.

#### 8.1.6.2.3 Cutting or Wash Samples

Occasionally, cutting or wash samples might be required as the boring is advanced. Cutting or wash samples should be handled and packaged as outlined for split-spoon samples. An estimate of the depth (or range of depth) from which the sample was obtained should be recorded on the log sheet. Samples are usually taken every 5 feet. Samples should be labeled in the manner outlined for jar samples.

### 8.1.6.3 Decontamination and Waste Handling

Waste handling and decontamination of equipment should be coordinated with the SM or designated field person before entering the site. Removing any possible sources of offsite contamination from the drilling equipment before beginning work will minimize the offsite transportation of waste upon completion of work and will minimize cross contamination while working onsite.

Between samples, the sampling equipment shall be decontaminated as approved by the SM or designated personnel. The decontamination procedure generally involves the following:

- Brush off visible mud or dirt; scrub and wash with clean water. Organic-free water, distilled water, or tap water may be used; the tap water source must be noncontaminated. (**Note:** Sample cleaning blanks will be submitted for analysis to assure adequacy of decontamination.)
- Scrub and wash with trisodium phosphate.
- Scrub and wash with methanol or acetone.
- Rinse with clean water, preferably de-ionized or distilled water. (See remarks above about clean water.)

Between boreholes, all casing, rods, samplers, and other equipment used in the boreholes must be decontaminated as approved by the SM. The cleaning process generally consists of steam cleaning or hosing the drilling equipment with a high-pressure hot water rinse. After cleaning, the drilling equipment must be placed on a clean surface on the driller's truck bed or wrapped in clean polyethylene sheeting.

Upon completion of drilling activities, all equipment including the drill rig and all casing, rods, tools, and miscellaneous equipment must be decontaminated before leaving the site, as approved by the SM. The drill rig and equipment are usually cleaned with a steam cleaner or mobile high-pressure hot water washer. Wipe tests may be used to determine the extent of remaining contamination, if any; this testing is particularly relevant when a commercial well driller has been used as a contractor.

Solid waste from the drilling should be placed in barrels following completion of each borehole or disposed of onsite with approval of the SM and EPA. Barrels containing solid wastes will be marked so the contents can be identified and stored in a secure area onsite (shed or fenced area), at the direction of the SM.

Fluids that are produced during drilling or well development or that are potentially contaminated during equipment decontamination will have to be contained onsite and analyzed for contamination. If shown to be uncontaminated, these fluids may be disposed of by an EPA- and SM-approved site-specific method. Contaminated fluids will be handled according to procedures specified in the site-specific Quality Assurance Project Plan (QAPjP). This consideration will be of particular importance at well locations adjacent to surface waters. To prevent a runoff, a fluid discharge containment trench may be excavated so that all fluids from drilling, well development, and decontamination can be diverted to the trench. One trench may be large enough to contain all fluids produced at a given borehole location. The trench is usually lined. Consideration must be given to proper security (fencing or lights) around a trench when personnel are absent from the site. Air emissions from the fluids in a trench should be monitored.

Closure of the trench or removal of the trench contents or other contained fluids must be planned before initiating any drilling. Trench contents may be allowed to drain into the soil; may be solidified by backfilling; or may be drained, pumped, or sucked dry, followed by removal of the liner and proper disposal. Samples may be taken from the trench fluids to determine the proper disposal methods. In some cases, the SM or designated personnel may direct that all fluids be contained in a mobile tank or drums for subsequent discharge at a location removed from surface waters. This location will be determined by the SM and is usually less than 1 mile from a given well. Care must be taken in transporting such potentially contaminated material on public roads to the collection point.

## 8.1.7 Region-Specific Variances

In general, site-specific conditions and the purpose of the project should be the main criteria for selection of drilling and sampling methods. However, regional variations from the methods recommended above might be necessary because of local availability of certain types of equipment. However, because information on variances can become dated rapidly, the user should contact the EPA RPM for current regional practices and requirements. Future changes will be incorporated in Revision 01 of this compendium.

### 8.1.7.1 Region I

The hydrogeologists in Region I of EPA do not permit the use of mud rotary drilling techniques to drill a boring for an unconsolidated zone monitoring well. Region I requires the performance of continuous split-spoon sampling during all drilling operations. Also, Region I requires permeability testing at regular 5-foot intervals during drilling operations.

### 8.1.7.2 Region IV

Region IV EPA personnel recommend the use of pesticide-grade isopropyl alcohol as a cleaning solvent in place of acetone or methanol.

### 8.1.7.3 Region IX

Region IX EPA personnel do not permit the use of hand augers in sampling for TCDD.

## 8.1.8 Information Sources

Ackel, W.L. *Basic Procedures for Soil Sampling and Core Drilling.* Scranton, Pennsylvania: Ackel Drill Co., Inc. 1976.

Barcelona, M.J., J.P. Gibb, J.A. Helfrid, and E.E. Garske. *Practical Guide for Groundwater Sampling.* SWS Contract Report 324. Champaign, Illinois: Illinois State Water Survey. 1985.

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Hvorslev, M.J. *Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes.* Vicksburg, Mississippi: Waterways Experiment Station. 1949. Reprinted by ASCE Engineering Foundation. 1965.

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## 8.2 TEST PITS AND EXCAVATIONS

### 8.2.1 Scope and Purpose

The scope and purpose of this subsection is to provide reference material for conducting test pit and trench excavations at hazardous waste sites. These reference materials provide general guidelines; consequently, project-specific plans take precedence.

### 8.2.2 Definitions

**Site Manager(SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

**Trenches or Test Pit**

Open shallow excavations, typically longitudinal (if a trench) or rectangular (if a pit), to determine the shallow subsurface conditions for engineering, geological, and soil chemistry exploration and/or sampling purposes. These pits are excavated manually or by a machine, such as a backhoe, clamshell, trencher excavator, or bulldozer.

### 8.2.3 Applicability

This subsection presents routine test pit or trench excavation techniques. Specialized techniques that are applicable only under certain conditions are not presented.

During the excavation of trenches or pits at hazardous waste sites, several health and safety concerns arise and control the method of excavation. All excavations that are deeper than 4 feet must be stabilized (before entry into the excavation) by bracing the pit sides using wooden or steel support structures. Personnel entering the excavation may be exposed to toxic or explosive gases and oxygen-deficient environments. In these cases, substantial air monitoring is required before entry, and appropriate respiratory gear and protective clothing is mandatory. There must be at least two persons present at the immediate site before entry by one of the investigators. The reader should refer to OSHA regulations 29 CFR 1926, 29 CFR 1910.120, and 29 CFR 1910.134.

Machine-dug excavations are generally not practical where a depth of more than about 15 feet is desired. These excavations are also usually limited to a few feet below the water table. In some cases, a pumping system may be required to control water levels within the pits, providing that pumped water can be adequately stored or disposed. If data on soils at depths greater than 15 feet are required, the data are usually obtained through test borings instead of test pits.

In addition, hazardous wastes may be brought to the surface by excavation equipment. This material, whether removed from the site or returned to the subsurface, must be properly handled.

### 8.2.4 Responsibilities

The SM or field team leader is responsible for developing the test pit program and instituting the program, including sample acquisition. A minimum two-person crew, in addition to the excavating equipment operator, is recommended for test pit work at a hazardous waste site. Larger crews may be required if unusually hazardous conditions may be encountered or the scope of work requires additional staffing. One person onsite must function as the health and safety officer to monitor compliance with health and safety requirements. Other duties that may be required include sampling operations, both chemical and/or geotechnical, and soil or rock descriptions. The personnel onsite may divide the required duties according to their capabilities. Where physical or geotechnical soil descriptions are required, a geologist should be included in the crew.

### 8.2.5 Records

Test pit logs should contain a sketch of pit conditions. In addition, at least one photograph with a scale for comparison should be taken of each pit. Included in the photograph should be a card showing the test pit number and site name. Test pit locations should be documented by typing in the location of two or more nearby permanent landmarks (trees, house, fence, etc.) and should be located on a site map. Surveying may also be required, depending on the requirements of each project. Other data to be recorded in the field logbook include the following:

- Name and location of job
- Date of excavation
- Approximate surface elevation
- Total depth of excavation
- Dimensions of pit
- Method of sample acquisition
- Type and size of samples
- Soil and rock descriptions
- Photographs
- Groundwater levels
- Organic gas or methane levels
- Other pertinent information, such as waste material encountered

## 8.2.6 Guidelines

### 8.2.6.1 Test Pit and Trench Construction

These guidelines describe the methods for excavating and logging test pits and trenches to determine subsurface soil and rock conditions.

Test pits and trenches may be excavated by hand or by power equipment to permit detailed explanation and clear under standing of the nature and contamination of the in situ materials. The size of the excavation will depend primarily on the following:

- The purpose and extent of the exploration
- The space required for efficient excavation
- The chemicals of concern
- The economics and efficiency of available equipment

Test pits normally have a cross section that is 4 to 10 feet square; test trenches are usually 3 to 6 feet wide and may be extended for any length required to reveal conditions along a specific line. The following table, which is based on equipment efficiencies, can give a rough guide for design consideration:

| Equipment | Typical Widths, in Feet |
|---|---|
| Trenching machine | 2 |
| Backhoe | 2 - 6 |
| Track dozer | 10 |
| Track loader | 10 |
| Excavator | 10 |
| Scraper | 20 |

Fifteen feet is considered to be the economical vertical limit of excavation. However, larger and deeper excavations have been used when special problems justified the expense.

The construction of test pits and trenches should be planned and designed in advance as much as possible. However, field conditions may necessitate revisions to the initial plans. The field supervisor should determine the exact depth and construction. The test pits and trenches should be excavated in compliance with applicable safety regulations as specified by the health and safety officer.

If the depth exceeds 4 feet and people will be entering the pit or trench, Occupational Safety and Health Administration (OSHA) requirements must be met: Walls must be braced with wooden or steel braces, ladders must be in the hole at all times, and a temporary guardrail must be placed along the surface of the hole before entry. It is advisable to stay out of test pits as much as possible; if possible, the required data or samples should be gathered without entering the pit. Samples of leachate, groundwater, or sidewall soils can be taken with telescoping poles, etc.

Stabilization of the sides of test pits and trenches, when required, generally is achieved by sloping the walls at a sufficiently flat angle or by using sheeting. Benching or terracing can be used for deeper holes.

Shallow excavations are generally stabilized by sheeting. Test pits excavated into fill are generally much more unstable than pits dug into natural in-place soil.

Sufficient space should be maintained between trenches or pits, to place soil that will be stockpiled for cover, as well as to allow access and free movement by haul vehicles and operating equipment. Excavated soil should be stock piled to one side, in one location, preferably downwind, away from the edge of the pit to reduce pressure on the pit walls.

Dewatering may be required to assure the stability of the side walls, to prevent the bottom of the pit from heaving, and to keep excavation dry. This is an important consideration for excavations in cohesionless material below the groundwater table. Liquids removed as a result of dewatering operations must be handled as potentially contaminated materials. Procedures for the collection and disposal of such materials are discussed in the site-specific QAPjP.

The overland flow of water from excavated saturated soils and the erosion or sedimentation of the stockpiled soil should be controlled. A temporary detention basin and a drainage system should be planned to prevent the contaminated wastes from spreading.

### 8.2.6.2 Sampling Techniques

Sampling from test pits can be performed by "disturbed" and "undisturbed" methods. Sampling should begin from within the pit or trench only after proper safety precautions have been initiated.

All samples collected should be identified on the test pit logs and in the field notebook. Information such as sample number, depth, type, volume, and method of collection is required. Preservation, packing, and shipping methods are specified elsewhere in this compendium (Sections 4, 5, and 6).

**Equipment:** The following is a list of equipment that may be needed for taking samples from test pits and trenches:

- Backhoe or other excavating machinery
- Shovels, picks, or scoops
- Sample containers (5-gal bucket with locking lid for large samples and 250-mL glass bottles for chemical analysis samples)

**Disturbed samples:** Disturbed samples are those that have been collected in a manner in which the in-situ physical structure and fabric of the soil have been disrupted. Disturbed sampling techniques typically include sampling from the walls or floors of the test pit by means of scraping or digging with a trowel, rockpick, or shovel. Large disturbed samples can be taken directly from the backhoe bucket during excavation; however, care must be taken to assure that the sample is actually from the unit desired and does not include slough or scraped material from the sides of the trench.

**Undisturbed samples:** "Relatively undisturbed" samples can be obtained from test pits. Typically, an undisturbed sample is collected by isolating by hand a large cube of soil at the base or side of the test pit. This sample can be cut using knives, shovels, and the like. Care is taken to keep disturbances to a minimum. After the block of soil is removed, it is placed in an airtight, padded container for shipment to the lab. The overexcavated sample is "trimmed" at the laboratory to the size required for the designated test. In some instances (e.g., in soft cohesive soil), it may be possible to get an undisturbed sample by pushing a Shelby tube sampling device into an undisturbed portion of the test pit and by using a backhoe.

**Waste samples:** Trenching and test pitting are excellent methods of obtaining waste samples from dumps and landfills. While borings may be useful at greater depths, drilling through a landfill or dump creates unusual hazards, such as hitting pockets of explosive gases; rupturing intact, buried containers; or potentially contaminating the transfer by penetrating confining layers beneath a landfill. Additionally, the samples gathered by drilling are not representitive of the heterogeneous conditions found in a landfill. Trenching and test pitting allow a larger, more representitive area to be observed, permit selection of specific samples from the pile of spoiled or stockpiled material (biased grab sampling), and, with reasonable precautions, allow the retrieval of intact, buried containers.

### 8.2.6.3 Backfilling of Trenches and Test Pits

Before backfilling, the onsite crew should photograph all significant features exposed by the test pit and trench and should include in the photograph a scale to show dimensions. Photographs of test pits should be marked to include site number, test pit number, depth, description of feature, and date of photograph. In addition, a geologic description of each photograph should be entered in the logbook. All photographs should be indexed and maintained for future reference.

After inspection, backfill material should be returned to the pit under the direction of the field supervisor.

If a low permeability layer is penetrated (resulting in groundwater flow from an upper contaminated flow zone into a lower uncontaminated flow zone), backfill material must represent original conditions or be impermeable. Backfill could consist of a soil-bentonite mix prepared in a proportion specified by the field supervisor (representing a permeability equal to or less than original conditions). Backfill should be covered by "clean" soil and graded to the original land contour. Revegetation of the disturbed area may also be required.

### 8.2.6.4 Decontamination

For decontamination procedures, the reader should refer to Subsection 8.1.6.3.

## 8.2.7 Region-Specific Variances

Site-specific conditions and project objectives dictate the methods of test pit or trench excavation and sampling. No region-specific variances from the methods described above are known. Decontamination procedures for sampling equipment vary with region. Most regions permit methane or acetone for a decontamination solution; however, some allow only isopropyl alcohol. Because information on variances can become dated rapidly, the user should contact the EPA RPM for current regional practices and requirements. Future changes and additional regional variances will be incorporated in Revision 01 of this compendium.

## 8.2.8 Information Sources

NUS Corporation. *NUS Operating Guidelines Manual.* Superfund Division, Sections 4.13 and 4.38.

U.S. Department of Interior. *The Earth Manual.* 2nd ed. U.S. Government Printing Office: Washington, D.C. 1980. 810 pp.

# 8.3 GEOLOGICAL RECONNAISSANCE AND GEOLOGICAL LOGGING

## 8.3.1 Scope and Purpose

This subsection describes geological reconnaissance studies and geological logging activities for field investigations of hazardous waste sites.

Geological reconnaissance studies require considerable professional judgment. Successful completion relies more on professional experience and insight than on acknowledged standards or procedures. Because there are no industry standards, this subsection describes basic methods, procedures, and activities to be accomplished or considered for a geological reconnaissance. Each site will require a special approach that will depend on the local geology, the amount of available data, the project schedule, and the judgment of the project geologist.

Geological logging of soil or rock materials derived from subsurface investigations is a more objective activity, and several industry standards exist for the physical description of earth materials. These standards will be described below.

## 8.3.2 Definitions

### Geological Reconnaissance Studies

The American Geological Institute (AGI) defines a geological reconnaissance as "a general, exploratory examination or survey of the main features (or certain specific features) of a region, usually conducted as a preliminary to a more detailed survey."

The geological reconnaissance, therefore, provides the basis for more detailed investigations by identifying the major geological or physical features at and near the hazardous waste site. Geological reconnaissance studies are conducted early in project site investigations as part of the site characterization process.

### Geological and Geophysical Logging

Geological and geophysical logging is a detailed, systematic, and sequential record of the progress of drilling a well or borehole, or of excavating pits and trenches.

The record of geological logging is kept on printed log forms and may include notes on the following:

- Soil and rock classifications and descriptions
- Outcrop descriptions
- Depths and thicknesses of the earth materials penetrated
- Groundwater conditions
- Origin and geologic structure(s)

- Drilling progress
- Borehole geophysical logging
- Sampling
- Type of equipment used
- Unusual or significant conditions
- Date of drilling, location of borehole, and so forth

Materials encountered are classified and described by obtaining samples or cuttings and by applying the standards described below.

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

## 8.3.3 Applicability

### 8.3.3.1 Geological Reconnaissance

Geological reconnaissance studies are applicable to most investigations of hazardous waste sites and are dependent on the existing database for the site. Sites having little existing information concerning site setting and relevant geologic features may require more detailed work than sites with a considerable database.

### 8.3.3.2 Geological Logging

Geological logging of subsurface explorations is always necessary to record events and conditions encountered in the field. Maintenance of acceptable log forms and adherence to established, or mandated procedures for material description, are critical to technically sound and defensible field investigations.

## 8.3.4 Responsibilities

The SM is ultimately responsible for determining that proper logging and geologic reconnaissance techniques are applied to the project. Because of the variability of geologic conditions from one site to another and the judgment required by such studies, an experienced project geologist with local knowledge should work with the SM to plan, implement, and evaluate the reconnaissance.

## 8.3.5 Procedures

### 8.3.5.1 Geological Reconnaissance

#### 8.3.5.1.1 General

Experienced personnel should plan and implement a cost-effective and technically sound reconnaissance study. The scope of the study will depend on anticipated problems and conditions at the site, coupled with professional judgment. The scope will vary depending on the following:

- Amount of available reference material and base maps
- Site accessibility
- Size of site and type of facility (landfill, tanks, industrial, other)
- Geologic setting of the site
- Site topography or geomorphology
- Anticipated subsurface and groundwater conditions
- Anticipated extent and type of contamination
- Level of personal protection required during the conduct of the reconnaissance
- Overall goal of the site investigation activities

#### 8.3.5.1.2 Methods

Hunt (1984) describes the basic steps of a geological reconnaissance as follows:

- Research of reference materials and collection of available data
- Terrain analysis based on topographic maps and remote sensing imagery
- Preparation of a preliminary geological map including (where appropriate) saprolite mapping, outcrop mapping with strike and measurements of structural features, and locating of springs and seeps
- Site reconnaissance to confirm and amplify the geological map, followed by preparation of the final version of the map
- Preparation of a subsurface exploration program based on anticipated conditions and data gaps

The proportion of field work to office work will vary from site to site.

References and data gathered to initiate the work may include any or all of the following historical or recent materials: geological maps and texts; soil surveys; hydrogeologic reports and well logs; topographic maps, air photos, and remote sensing imagery; climatic data; geotechnical engineering reports for the area; and site-related data and reports.

The basic objectives of the geological reconnaissance are to determine regional geologic setting and site-specific geologic conditions including the following:

- Determination of bedrock geology and major structural features
- Determination of the geology of unconsolidated overburden and soil deposits
- Identification of actual or potential aquifers and water-bearing units and their physical properties
- Climatic and topographic conditions affecting groundwater recharge and discharge, erosion, flooding, and surface water conditions of interest
- Identification of potential pathways for contaminant migration
- Geologic conditions, hazards, or constraints that could contribute to offsite contaminant migration or that might preclude certain remedial alternatives

Specific items of interest include outcrops, springs, seeps, leachate outbreaks, and surface drainage features. Compton (1962) presents a detailed list of field data collection techniques.

The reconnaissance study may sometimes be accompanied by more in-depth exploratory techniques when little is known about the site, when the site is especially complex, or when more detailed geologic or hydrogeologic site characterization is necessary. The scope of more detailed studies will also be project specific and must build on data previously gathered. As with reconnaissance level efforts, the level of effort for detailed geological investigations should be designed to be commensurate with potential remedial technologies and overall project goals. For the majority of sites the emphasis of the detailed studies is on hydrogeology. These detailed studies include the following:

- Drilling of hydrogeologic test holes and soil borings, which are logged in the field by geologists
- In situ testing for permeability and other aquifer and aquitard characteristics
- Installing groundwater monitoring wells
- Determining groundwater flow-rates and directions
- Integrating site-specific hydrogeology into the regional hydrogeologic regime

In addition to these tasks, certain geotechnical or geological elements of the site may be explored by using test pits, boreholes, or geophysics. These activities can further define site conditions and develop engineering criteria for the design of remedial alternatives. Well drilling and geophysical techniques are described in Subsection 8.1. These techniques are subject to site-specific health and safety and quality assurance procedures.

### 8.3.5.2 Geological Logging

#### 8.3.5.2.1 General

Geological logging, as previously defined, includes keeping a detailed record of drilling (or excavating) and a geological description of materials on a prepared form. Geological logs are used for all types of drilling and exploratory excavations and include descriptions of both soil and rock. General guidance for logging soils and rock is provided below.

#### 8.3.5.2.2 Methods - Soils

When drilling in soils or unconsolidated deposits, the log should be kept on a standard soil boring log form (Exhibit 8.3-1). The following basic information should be entered on the heading of each log sheet:

- Project name and number
- Boring or well number
- Location (approximate in relation to an identifiable landmark; will be surveyed. See Section 14, Land Surveying, Aerial Photography, and Mapping).
- Elevation (approximate at the time; will be surveyed. See Section 14, Land Surveying, Aerial Photography, and Mapping).
- Name of drilling contractor
- Drilling method and equipment
- Water level
- Start and finish (time and date)
- Name of logger

The following technical information is recorded on the logs:

- Depth of sample below surface
- Sample interval
- Sample type and number
- Length of sample recovered
- Standard penetration test (ASTM-D1586) results if applicable
- Soil description and classification
- Graphic soil symbols

## Exhibit 8.3-1
## SOIL BORING LOG

| | |
|---|---|
| **PROJECT NUMBER** | **BORING NUMBER**<br>SHEET OF |

## SOIL BORING LOG

PROJECT ______ LOCATION ______

ELEVATION ______ DRILLING CONTRACTOR ______

DRILLING METHOD AND EQUIPMENT ______

WATER LEVEL AND DATE ______ START ______ FINISH ______ LOGGER ______

| ELEVATION | DEPTH BELOW SURFACE | SAMPLE | | | STANDARD PENETRATION TEST RESULTS | SOIL DESCRIPTION | SYMBOLIC LOG | COMMENTS |
|---|---|---|---|---|---|---|---|---|
| | | INTERVAL | TYPE AND NUMBER | RECOVERY | 6"-6"-6" (N) | NAME, GRADATION OR PLASTICITY, PARTICLE SIZE DISTRIBUTION, COLOR, MOISTURE CONTENT, RELATIVE DENSITY OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY, USCS GROUP SYMBOL | | DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS AND INSTRUMENTATION |
| | | | | | | | | |

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In addition to the items listed above, all pertinent observations about drilling rate, equipment operation, or unusual conditions should be noted. Such information might include the following:

- Size of casing used and method of installation
- Rig reactions such as chatter, rod drops, and bouncing
- Drilling rate changes
- Depth and percentage of fluid losses
- Changes in fluid color or consistency
- Material changes
- Zones of caving or heaving

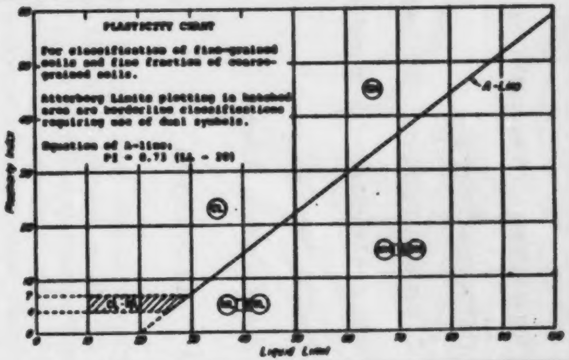
### 8.3.5.2.3 Soil Description

Description of soils (well logging) should be done in accordance with the Unified Soil Classification System (USCS) as described in ASTM D2487-69 (1975): Test Method for Classification of Soils for Engineering Purposes (see Exhibit 8.3-2). The approach and format should generally conform to ASTM D2488-69(1975): Recommended Practice of Description of Soils (Visual-Manual Procedure). Alternatively, the Burmeister system of soil description may be used, although the use of this system seems to be concentrated in the Northeast. The complete title of the Burmeister system can be found in the references. Because the Burmeister system relies heavily on handling the soil, it should not be used in areas of significant soil contamination.

The soil description should be concise and should stress major constituents and characteristics. Soil descriptions should be given in a consistent order and format. The following order is as given in ASTM D2488:

- 1. **Soil Name:** The basic name of the predominant constituent and a single-word modifier indicating the major subordinate constituent.
- 2. **Gradation or Plasticity:** For granular soil (sands or gravels) that should be described as well- graded, poorly graded, uniform, or gap-graded, depending on the gradation of the minus 3-inch fraction. Cohesive soil (silts or clays) should be described as nonplastic, slightly plastic, moderately plastic, or highly plastic, depending on the results of the manual evaluation for plasticity as described in ASTM D2488.
- 3. **Particle Size Distribution:** An estimate of the percentage and grain-size range of each of the soil's subordinate constituents with emphasis on clay-particle constituents. This description may also include a description of angularity. This parameter is critical for assessing hydrogeology of the site and should be carefully and fully documented.
- 4. **Color:** The basic color of the soil. (Refer to Munsell color charts.)
- 5. **Moisture Content:** The amount of soil moisture, described as dry, moist, or wet.
- 6. **Relative Density or Consistency:** An estimate of density of a granular soil or consistency of a cohesive soil, usually based on standard penetration test results (see Exhibit 8.3-3).

# Exhibit 8.3-2
# UNIFIED SOIL CLASSIFICATION

| MAJOR DIVISIONS | | | GROUP SYMBOLS | TYPICAL NAMES | CLASSIFICATION CRITERIA | | |
|---|---|---|---|---|---|---|---|
| COARSE-GRAINED SOILS<br>More than 50% retained on No. 200 sieve* | GRAVELS<br>50% or more of coarse fraction retained on No. 4 sieve | CLEAN GRAVELS | GW | Well-graded gravels and gravel-sand mixtures, little or no fines | Classification on basis of percentage of fines<br>Less than 5% Pass No. 200 sieve GW, GP, SW, SP<br>More than 12% Pass No. 200 sieve GM, GC, SM, SC<br>5% to 12% Pass No. 200 sieve Borderline Classification requiring use of dual symbols | $C_u = D_{60}/D_{10}$ Greater than 4<br>$C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 | |
| | | | GP | Poorly graded gravels and gravel-sand mixtures, little or no fines | | Not meeting both criteria for GW | |
| | | GRAVELS WITH FINES | GM | Silty gravels, gravel-sand-silt mixtures | | Atterberg limits plot below "A" line or plasticity index less than 4 | Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols |
| | | | GC | Clayey gravels, gravel-sand-clay mixtures | | Atterberg limits plot above "A" line and plasticity index greater than 7 | |
| | SANDS<br>More than 50% of coarse fraction passes No. 4 sieve | CLEAN SANDS | SW | Well-graded sands and gravelly sands, little or no fines | | $C_u = D_{60}/D_{10}$ Greater than 6<br>$C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 | |
| | | | SP | Poorly graded sands and gravelly sands, little or no fines | | Not meeting both criteria for SW | |
| | | SANDS WITH FINES | SM | Silty sands, sand-silt mixtures | | Atterberg limits plot below "A" line or plasticity index less than 4 | Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols |
| | | | SC | Clayey sands, sand-clay mixtures | | Atterberg limits plot above "A" line and plasticity index greater than 7 | |
| FINE-GRAINED SOILS<br>50% or more passes No. 200 sieve* | SILTS AND CLAYS<br>Liquid limit 50% or less | | ML | Inorganic silts, very fine sands, rock flour, silty or clayey fine sands |  | | |
| | | | CL | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays | | | |
| | | | OL | Organic silts and organic silty clays of low plasticity | | | |
| | SILTS AND CLAYS<br>Liquid limit greater than 50% | | MH | Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts | | | |
| | | | CH | Inorganic clays of high plasticity, fat clays | | | |
| | | | OH | Organic clays of medium to high plasticity | | | |
| Highly Organic Soils | | | PT | Peat, muck and other highly organic soils | Visual-Manual Identification. See ASTM Designation D 2488 | | |

* Based on the material passing the 3-in. (75-mm) sieve.

SOURCE: ASTM D 2487

## Exhibit 8.3-3
## RELATIVE DENSITY OF NONCOHESIVE SOIL

| Blows/Ft | Relative Density | Field Test |
|---|---|---|
| 0-4 | Very loose | Easily penetrated with 1/2-inch steel rod pushed by hand |
| 5-10 | Loose | Easily penetrated with 1/2-inch steel rod pushed by hand |
| 11-30 | Medium | Easily penetrated with 1/2-inch steel rod driven with 5-lb hammer |
| 31-50 | Dense | Penetrated a foot with 1/2-inch steel rod driven with 5-lb hammer |
| >50 | Very dense | Penetrated only a few inches with 1/2-inch steel rod driven with 5-lb hammer |

## CONSISTENCY OF COHESIVE SOIL

| Blows/Ft | Consistency | Pocket Penetrometer (TSF*) | Torvane (TSF) | Field Test |
|---|---|---|---|---|
| <2 | Very soft | <0.25 | <0.12 | Easily penetrated several inches by fist |
| 2-4 | Soft | 0.25-0.5 | 0.12-0.25 | Easily penetrated several inches by thumb |
| 5-8 | Firm | 0.50-1.0 | 0.25-0.5 | Can be penetrated several inches by thumb with moderate effort |
| 9-15 | Stiff | 1.0-2.0 | 0.5-1.0 | Readily indented by thumb but penetrated only with great effort |
| 16-30 | Very stiff | 2.0-4.0 | 1.0-2.0 | Readily indented by thumbnail |
| >30 | Hard | >4.0 | >2.0 | Indented with difficulty by thumbnail |

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*TSF– Tons per square foot

- 7. **Soil Texture and Structure:** Description of particle size distribution, arrangement of particles into aggregates, and their structure. This description includes joints, fissures, slicken sides, bedding, veins, root holes, debris, organic content, and residual or relict structure, as well as other characteristics that may influence the movement or retention of water or contaminants.

- 8. **Relative Permeability:** An estimate of the permeability based on visual examination of materials (e.g., high permeability for coarse sand and gravel versus low permeability for silty clay). The estimate should address presence and condition of fractures (open, iron-stand, calcite-filled, open but clay-lined, etc.), as well as fracture density and orientation.

- 9. **Local Geologic Name:** Any specific local name or a generic name (i.e., alluvium, loess).

- 10. **Group Symbol:** Unified Soil Classification System of symbols (see Exhibit 8.3-2).

The soil logs should also include a complete description of any tests run in the borehole; placement and construction details of piezometers, wells, and other monitoring equipment; abandonment records; geophysical logging techniques used; and notes on readings obtained by air monitoring instruments.

### 8.3.5.2.4 Rock Methods

When coring in rock, keep the log on a standard rock core log form (see Exhibit 8.3-4). Basic information should be entered on the heading, as described in the soil section. The following technical information is entered in the log:

- Depth
- Core length
- Coring rate in minutes per foot
- Fluid gain or loss
- Core loss
- Percentage of recovery
- Core breakage due to discontinuities
- Total core breakage
- Number of breaks per foot
- Rock classification and lithology

In addition to the items listed above, pertinent observations concerning drilling rate, equipment operation, or unusual conditions should be noted. Such information might include the following:

- Casing type and diameter
- Type of drilling fluid
- Rig reactions

## Exhibit 8.3-4
## ROCK CORE LOG

SHEET ____ OF ____

PROJECT NUMBER

ROCK CORE LOG

PROJECT ______________________ LOCATION ______________________

DRILLING METHOD ______________________ DRILLERS & EQUIPMENT ______________________

ELEVATION __________ ORIENTATION ______________________ BORE HOLE: __________

WATER LEVEL __________ DATE: __________ START: __________ FINISH: __________ INSPECTOR __________

| DEPTH | COMMENTS | CORE RUN LENGTH AND RECOVERY (%) | CORE LOSS ZONE | BOX NUMBER | DISCONTINUITIES | | | LITHOLOGY | | GRAPHIC LOG |
|---|---|---|---|---|---|---|---|---|---|---|
| | TESTS<br>INSTRUMENTATION<br>CORING RATE AND SMOOTHNESS<br>CORING FLUID LOSS | | | | RQD | FRACTURES PER FOOT | DESCRIPTION<br>TIGHTNESS<br>PLANARITY<br>SMOOTHNESS<br>FILLING, STAINING<br>ORIENTATION | MINERALOGY<br>CLASSIFICATION<br>COLOR<br>GRAIN SIZE<br>ALTERATION | CEMENTATION<br>HARDNESS<br>WEATHERED STATE | |
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- Depth and percentage of fluid losses
- Material changes
- Zones of caving

### 8.3.5.2.5 Rock Classification

The description of rock should be done in an orderly and systematic fashion. The following order is recommended:

- 1. **Lithology and Texture:** Geological name of the rock and its mineral composition (the geological name, such as granite, basalt, or sandstone, usually describes the rock's origin). Description of how grains are arranged or bound together (i.e., interlocking, cemented, or laminated-foliated; Deere, 1963)
- 2. **Color:** The basic color of the rock, modified by light, medium, or dark.
- 3. **Hardness:** Terms used to describe hardness are given on subsequent pages.

| Descriptive Term | Defining Characteristics |
|---|---|
| Very hard | Cannot be scratched with knife. Does not leave a groove on the rock surface when scratched. |
| Hard | Difficult to scratch with knife. Leaves a faint groove with sharp edges. |
| Medium | Can be scratched with knife. Leaves a well-defined groove with sharp edges. |
| Soft | Easily scratched with knife. Leaves a deep groove with broken edges. |
| Very soft | Can be scratched with a fingernail. |

- 4. **Weathering:** Terms used to describe weathering are described below:

| Descriptive Term | Defining Characteristics |
|---|---|
| Fresh | Rock is unstained. May be fractured, but discontinuities are not stained. |
| Slightly | Rock is unstained. Discontinuities show some staining on the surfaces of rocks, but discoloration does not penetrate rock mass. |
| Moderate | Discontinuity surfaces are stained. Discoloration may extend into rock along discontinuity surfaces. |
| High | Individual rock fragments are thoroughly stained and can be crushed with pressure hammer. Discontinuity surfaces are thoroughly stained and may be crumbly. |
| Severe | Rock appears to consist of gravel-sized fragments in a "soil" matrix. Individual fragments are thoroughly discolored and can be broken with fingers. |

- 5. **Grain Size:** Term that describes fabric as fine-grained, medium-grained, or coarse-grained.

- 6. **Description of Bedding or of Joint or Fracture Spacing:** Description should be according to the following:

| Spacing | Joints | Bedding or Foliation |
|---|---|---|
| < 2 in. | Very close | Very thin |
| 2 in. to 1 ft | Close | Thin |
| 1 ft to 3 ft | Moderately close | Medium |
| 3 ft to 10 ft | Wide | Thick |
| > 10 ft | Very wide | Very thick |

(after Deere, 1963)

- 7. **Discontinuity Descriptions:** Terms that describe number, depth, and type of natural discontinuities. Also describe orientation, staining, planarity, alteration, joint or fracture fillings, and structural features.

- 8. **Local Geological Name:** Term used to assign local geological name, if appropriate, and to identify stratigraphic equivalents, if applicable.

The rock logs should also include a complete description of the mineralogy of the rock, of any tests run in the bore hole, and of placement and construction details of piezometers, wells, and other rig monitoring devices.

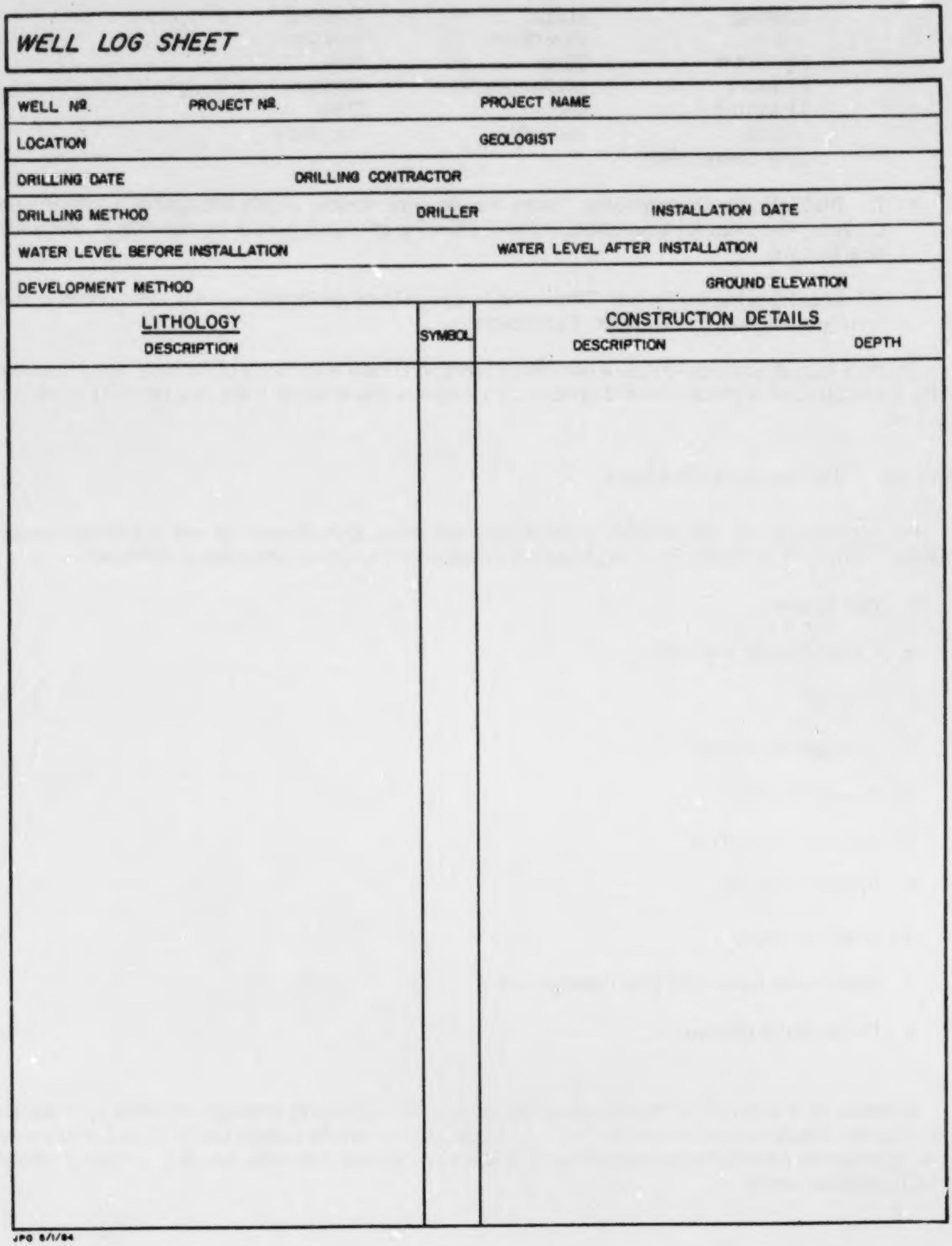
### 8.3.5.2.6 Well Completion Diagrams

For each monitoring well installed, a monitoring well completion diagram or well log should be submitted. This form (Exhibit 8.3-5) should contain information in the appropriate column as follows:

- Well number
- Project number and name
- Location
- Geologist or engineer
- Ground elevation
- Well installation date
- Drilling contractor
- Drilling methods
- Water levels before and after development
- Development method

Columns for a summary of the lithologies encountered during drilling, lithologic or USCS symbols, and construction details are shown on the form. The construction details include depth of well, screen, and riser; appropriate pipe diameters; backfill types and elevations; and pipe materials (e.g., polyvinyl chloride (PVC), stainless, black).

## Exhibit 8.3-5
## BLANK WELL LOG SHEET



*WELL LOG SHEET*

| | | |
|---|---|---|
| WELL NO. | PROJECT NO. | PROJECT NAME |
| LOCATION | | GEOLOGIST |
| DRILLING DATE | DRILLING CONTRACTOR | |
| DRILLING METHOD | DRILLER | INSTALLATION DATE |
| WATER LEVEL BEFORE INSTALLATION | | WATER LEVEL AFTER INSTALLATION |
| DEVELOPMENT METHOD | | GROUND ELEVATION |

| LITHOLOGY | SYMBOL | CONSTRUCTION DETAILS | |
|---|---|---|---|
| DESCRIPTION | | DESCRIPTION | DEPTH |
| | | | |

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## Exhibit 8.3-6
## COMPLETED WELL LOG SHEET

### WELL LOG SHEET

WELL NO. MW.3 PROJECT NO. 0758.16 PROJECT NAME SWOPE OIL CO.
LOCATION PENNSAUKEN, N.J. GEOLOGIST SJ CONTI
DRILLING DATE 6-21-84 DRILLING CONTRACTOR HYDRO GROUP
DRILLING METHOD MUD ROTARY DRILLER JOE YORT INSTALLATION DATE 6-25-84
WATER LEVEL BEFORE INSTALLATION WATER LEVEL AFTER INSTALLATION 82.55 7-6-84
DEVELOPMENT METHOD COMPRESSED AIR GROUND ELEVATION

| LITHOLOGY<br>DESCRIPTION | SYMBOL |
|---|---|
| 0-5-Loose, Orange Brown Silty Sand, Some gravel-Trace Organic Matl. | SM |
| 5 35-Medium Dense to Dense, Yellow Brown Gray, Alternating layers of sandy clay and clayey sand. Sand content increasing with depth. | SC |
| 35-54-Loose to Medium Dense, Yellow Brown, Medium to Coarse Sand, trace clay lenses Subangular sand grains. | SP |
| 54-64-Loose yellow brown, Clayey Sand Trace fine gravel. Subangular Sand grains | SC |
| 64-79-Loose to Medium Dense, Yellow Brown, Fine to Medium Sand, Trace clay and Fine gravel. Subangular Sand grains. | SM |
| 79-83-Dense, Light gray Brown, Medium to coarse Sand, trace fines and gravel. (Subangular grains.) | SP |
| 83-84-Stiff, v. light gray clay lens | CL |
| 84-125-Medium Dense to Dense Brown gray medium to coarse Sand-Trace fine gravel and trace clay. Subangular to Subrounded sand grains | SP |
| 125-132-Dense Brown gray Sand and gravel, trace of clay lenses. Subangular to subrounded grains. | SW |
| 132-136 Very Stiff, Very light gray Silty clay-Trace fine Sand. | CL |

CONSTRUCTION DETAILS

DESCRIPTION

DEPTH

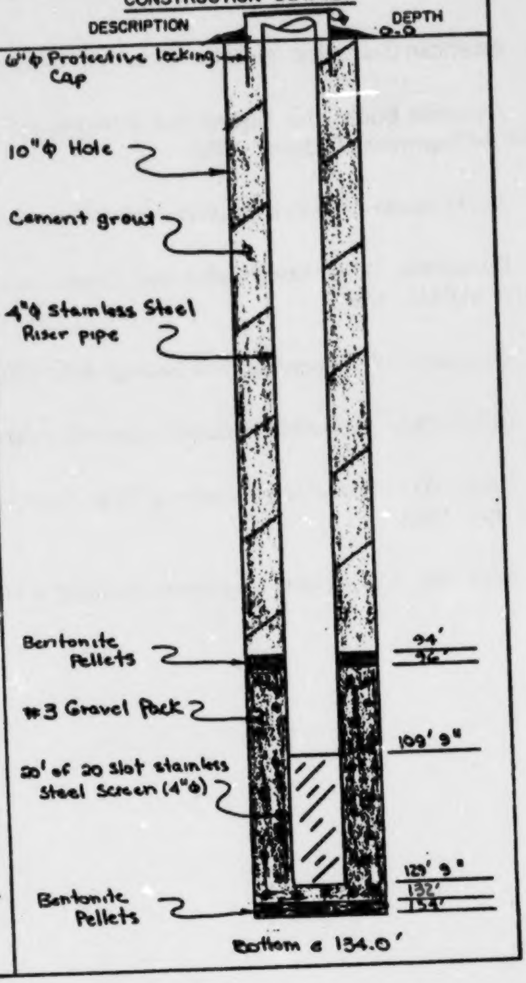
0.0
6"ϕ Protective locking Cap
10"ϕ Hole
Cement grout
4"ϕ Stainless Steel Riser pipe
Bentonite Pellets
94'
96'
#3 Gravel Pack
109' 9"
20' of 20 slot stainless Steel Screen (4"ϕ)
129' 9"
132'
134'
Bentonite Pellets
Bottom @ 134.0'

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Exhibit 8.3-6 is an example of a completed well log sheet. This form accompanies the rock core and soil boring logs to provide detailed information on borehole stratigraphy and monitoring well installation.

### 8.3.6 Region-Specific Variances

Site-specific conditions and project objectives will be the main criteria for methods used for geological reconnaissance and logging. No regional variations in the methods described above are known, but variations in reporting formats do exist. However, some regions prefer the Burmeister soil identification system. Because information on variances can become outdated rapidly, users of this section should consult the EPA region in which the logging will be done. Future changes will be incorporated in Revision 01 of this compendium.

### 8.3.7 Information Sources

American Geological Institute. *Glossary of Geology.* Washington, D.C. 1974.

American Society for Testing and Materials (ASTM) D2487 - *Standard Test Method for Classification of Soils for Engineering Purposes.* 1983.

ASTM D2488 - *Standard Recommended Practice for Description of Soils* (Visual-Manual Procedure). 1983.

Burmeister, D.M. *Identification and Classification of Soils—An Appraisal and Statement of Principles.* ASTM STP113. 1951

Compton, R.R. *Manual of Field Geology.* John Wiley and Sons, Inc. 1962.

CH2M HILL. *PMO Field Manual for Subsurface Exploration.* 1982.

Deere, D.U. *Technical Description of Rock Cores for Engineering Purposes.* Rock Mechanics Engineering Geology. 1963.

Hunt, R.E. *Geotechnical Engineering Investigation Manual.* McGraw-Hill: New York. 1984.

# 8.4 GEOPHYSICS

## 8.4.1 General Considerations

### 8.4.1.1 Scope and Purpose

This document provides general guidance for the planning, selection, and implementation of geophysical surveys that may be conducted during investigations of hazardous waste sites. Each of six commonly used methods are discussed from the standpoint of applicability to site investigation, procedures for implementation, survey design, and miscellaneous method-specific considerations. Emphasis is placed on the practical understanding of each method with a minimal amount of theoretical explanation being offered in the main body of the text. For those readers who may desire a more rigorous understanding, however, theoretical considerations have been included in the appendix.

### 8.4.1.2 Definitions

**Amplitude**
The maximum vertical displacement from equilibrium in a wave.

**Anomaly**
An electromagnetic (EM) reading that deviates from the typical site background reading and is generally caused by the presence of an irregularity or target.

**API**
American Petroleum Institute.

**Array**
The configuration of electrodes in resistivity surveys.

**Body Wave**
A "seismic wave" that travels through the interior of the earth and is not related to any boundary surface. A body wave may be either longitudinal ($P$-wave) or transverse ($S$-wave). (Glossary of Geology)

**Bulk Density**
The weight of an object or material divided by its volume, including the volume of its pore spaces.

**Circuit Potential**
Measured electrical voltage drop or gain.

**Compressional Wave**
That type of seismic body wave that involves particle motion (alternating compression and expansion) in the direction of propagation. It is the fastest of the seismic waves and is also known as a $P$-wave.

**Confidence Interval**
The statistical level of probability of accomplishing a given task, such as detecting a target.

**Critical Angle**
The least "angle of incidence" at which there is total reflection when electromagnetic radiation passes from one medium to another, less refracting medium. (Glossary of Geology)

**Critical Distance**

In refraction seismic work, that source-to-receiver distance at which the direct wave in an upper medium is matched in arrival time by that of the refracted wave from the medium below, the refracted wave having a greater velocity.

**Crossover Distance**

The source to receiver distance beyond which head waves from a deeper refractor arrive ahead of those from a shallower refractor.

**Cultural**

An anomaly or feature that is attributable to human development, such as buried drums or utility lines.

**Dead Time**

Measurement errors in nuclear logging occurring from the inability to record all of the pulse energy within the resolving time.

**Density**

Mass per unit volume (g/cm$^3$). Bulk rock densities vary mainly because of porosity and range from 1.9 to 2.8 g/cm$^3$.

**Dynamic Correction**

Seismic data must be corrected for normal moveout (NMO), which is the increase in arrival time of a reflection event, resulting from an increase in the distance from source to receiver or from dip of the reflector. Each trace has to be shifted by a different amount at different travel time to line up the primary reflections.

**Echo Profile**

The graphic representation of time-delayed Ground Penetrating Radar (GPR) impulses.

**Effective Porosity**

The porosity that involves those pore spaces which are interconnected and, therefore, effective in transmitting fluids.

**Electric Logs**

The generic term for a well log that displays electrical measurements of induced current flow between electrodes. Electric logs discussed in this sub-section include only single-point resistivity and spontaneous potential.

**Electrodes**

A ground-contacting metallic conductor used to apply current or measure the circuit potential.

**Fall-Off Rate**

The rate of decay of an anomaly with respect to distance.

**Fermat's Principle**

A seismic wave will follow the path that takes less time between two points rather than follow variations of this path. Such a path is called a minimum- time path.

**Gamma**

A unit of magnetic field. 1 gamma = 10$^{-5}$ gauss = 10$^{-9}$ tesla. In the International System of Units (SI units), 1 tesla = 1 kg amp sec$^2$.

**Law of Reflection**

The angle of incidence equals the angle of reflection.

**Logging Speed**

The speed at which the sonde traverses the borehole (typically in feet per minute).

**Magnetic Dipole**

A pair of magnetic poles of opposite signs and equal strengths that are close together so that the interaction of these poles is detectable.

**Magnetic Monopole**

A single magnetic pole of either positive or negative sign that is spatially separated from a magnetic pole of opposite sign so that there is no detectable interaction between the poles.

**Magnetic Moment**

The strength of a magnetic dipole.

**Magnetic Susceptibility**

A measure of the degree to which a substance may be magnetized.

**Multichannel Seismic**

Geophone groups and shotholes used in various combinations so that reflections are recorded from the same portion of the subsurface a number of times. Also referred to as common-depth point (CDP) shooting.

**Noise**

Variation in data because of an undesirable influence.

**Nuclear Logs**

The generic term for a well log that either measures natural or induces and measures radioactive isotopes in the borehole environment. Discussion in this text is limited to natural gamma, gamma-gamma, and neutron.

**Ray Parameter**

A function $P$ that is constant along a given seismic ray when horizontal velocity is constant.

Defined as:

$$\frac{\sin i}{V1} = 1$$

where velocity = $V$ and $i$ is the angle of wave incidence.

**Resistivity**

The ability of a material to resist the flow of electrical current.

**Shear wave**

A seismic body wave propagated by a shearing motion that involves oscillation perpendicular to the direction of propagation. The shear wave doesn't travel through liquids, and it arrives later than the $P$-wave. It is also known as an $S$-wave.

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

**Snell's Law**

When a seismic wave encounters a boundary between two layers of different seismic velocities, the direction of wave propagation changes so that the sine of the angle of wave incidence ($i$) divided by the seismic velocity ($V_0$), of the overlying medium equals the sine of the angle of wave refraction ($i_r$), divided by the seismic velocity ($V_1$), of the underlying medium.

$$P = \frac{\sin i}{V_0} = \frac{\sin i_r}{V_1} = \frac{\sin i_r}{V_0}$$

where ($i_r$) is the angle of wave reflection and ($p$) is the ray parameter.

**Sonde**

The elongated cylindrical tool assembly used in a borehole to acquire well log information.

**Specific Yield**

The ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity, to the volume of that mass.

**Spectrum**

Amplitude and phase characteristics as a function of frequency for the components of a seismic wavelet.

**Static Corrections**

Corrections applied to seismic data to compensate for the effects of variations in elevation, and weathered layer thickness by referencing all data to a datum plane. Such corrections are independent of time, the amount of shift being the same for all points on any trace.

**Surface Wave**

A "seismic wave" that travels along the surface of the earth or parallel to the earth's surface. Surface waves include Rayleigh waves, Love waves, and coupled waves.

**Target**

The specific focus (or purpose) of an EM survey, such as buried drums or trench boundaries.

**Thermal Convection**

The transfer of heat by vertical movements in the borehole because of density differences caused by heating from below.

**Total Porosity**

The ratio of the void volume of a porous medium to the total volume. This is generally expressed as a percentage.

### 8.4.1.3 Responsibilities

The SM, in conjunction with the EPA RPM, must clearly define the objectives and information desired from the geophysical efforts. Site Managers are responsible for determining which geophysical techniques will provide data to permit meeting the established objectives. Site Managers are also responsible for coordinating safety considerations, planning fieldwork, arranging for quality assurance/quality control (QA/QC), and providing technical assistance. Geophysical task leaders are responsible for site reconnaissance, identification of potential problems, estimation of project effectiveness, acquisition of equipment, onsite supervision, and data interpretation.

Electromagnetic techniques have been adapted for downhole applications. These can be useful in defining the vertical extent of a contaminant zone. Some systems work inside PVC or Teflon monitoring well casings. For further information on airborne, borehole, or surface EM instruments, the reader should consult the subsections on theory and interpretation and the manufacturer references listed later in this compendium.

### 8.4.1.4 Records and Inspection

#### 8.4.1.4.1 Calibration

Dated records of geophysical equipment calibration, whether performed in the field or in the laboratory, should be kept in the equipment management files and in the appropriate project file. Calibration is used to establish the reliability and accuracy of the equipment; it typically includes an internal circuit check and actual field trials (e.g., testing over a known target). Equipment that historically exhibits fluctuation in calibration should always be checked before and after field use. The equipment serial number should be recorded on the calibration records. If equipment is recalled by the manufacturer, the recall should be explained in the proper file. The various techniques and instruments available make it prohibitive to outline in this compendium the specific calibration procedures to be followed for each instrument. For those details, the reader should consult the manufacturer's manual pertaining to the particular instrument in use.

#### 8.4.1.4.2 Field Notes

Data and notes should be entered into a bound field logbook with sequentially numbered pages. At a minimum, each logbook page should include the names of the equipment operators; who kept the notes, if different from operator; survey date; name and project number of the site; line number; position (station) number; survey direction (heading north or south); raw data; and any specific notes that relate to the survey (such as surface metal, weather conditions, and topographic changes. This data logbook should be entered into the project field and stamped "original." Typed copies of the data may be included with the survey report. At the conclusion of field activities, a report specifying the dates of fieldwork, observations, personnel, and equipment involved should be submitted to the project file.

#### 8.4.1.4.3 Data Reduction

There are several accepted ways to present geophysical data. Data profiles can be useful for estimating anomaly depth and lateral extent along a survey line. For defining site patterns and lateral extent between lines, a contour map may be more useful than a profile. Three-dimensional maps are becoming more common (generated with the aid of computers) and can be extremely useful for site characterization. Computer programs should be examined for accuracy, because many programs that are unsuitable are available, particularly those programs with contouring functions. A percentage (such as 10 percent) of computer-plotted points should be manually checked for accuracy.

Specific calculations can involve differential and integral calculus; however, these equations may become theoretical, time consuming, and subject to interpretation. In general, graphic analysis may be more straightforward, cost effective, and not as likely to be challenged in litigation. Very detailed interpretations of some data are possible but should be attempted only by experienced personnel. Theoretically, it is possible to determine such things as size, shape, orientation, and depth of a conductor.

Parallel survey lines can be used to define long linear features such as contaminant plumes or faults. Some features are mapped by only a few anomalous readings; others are mapped by looking for anomalous trends. The decision to search for a few anomalous readings or trends is based mainly on the detail of the survey grid and the size (and type) of the feature. Conclusions based on single-point anomalies should be used cautiously, because these anomalies may be solely the result of a transcription error and not some site feature. A full discussion of interpretation theory and calculations is beyond the scope of this compendium.

#### 8.4.1.5 Use of Geophysics

Project management personnel should view geophysical methods as a tool to guide investigations of hazardous waste sites. Geophysics is a proven indirect investigative technique that should not be viewed as an absolute answer, because the methods are not part of an exact science. The final product of a successful geophysical survey is an experienced geophysicist's interpretation, which is not always definitive or conclusive. The results are interpretative and need to be routinely checked and confirmed by direct physical confirmation methods ("ground truthing," such as test pit excavation, drilling, and so forth).

Geophysics can be a cost-effective tool in providing extensive low-cost information and project guidance about successive, more costly phases.

#### 8.4.1.6 Procedures

The SM should confer with the staff geophysicist to determine the applicability of the method to site-specific conditions and objectives. To identify site-specific technical problems, the geophysicist should examine site reports, drilling logs, air photos, and other data that may exist. In addition, the SM and the geophysicist should conduct a site reconnaissance to identify any problems that may inhibit the study. Cultural features such as power lines, surface metal, and radio transmitters may have a detrimental effect on the data acquisition or interpretation. Identification of these potential problems during a site reconnaissance may have such an impact on the survey that the survey area may be modified, or geophysics may not be selected for use at that particular site. Finally, the Site Manager should inform the geophysicist of any related or dependent phases of work so that the geophysical survey may be completed in a timely manner and the interpretation may be used to provide guidance for subsequent tasks.

Most geophysical surveys are carried out over a grid or a series of lines within the study area. Stations at which measurements are taken or energy put into the ground (for those methods that involve an outside source of energy) are usually spaced at regular intervals designed by the geophysicist to produce optimum results for the study objectives. Although initial line placement can be done at the project management level, detailed line placement and surveying should be done only by qualified technical staff members.

All fieldwork should be done under the supervision of the staff geophysicist with daily data reduction and review being mandatory. The geophysicist should also supervise the daily reporting of all field data, which at a minimum should include all field notes, maps, work sheets, and raw data tabulation (including any x,y coordinates and measured values).

#### 8.4.1.7 Information Sources

Information sources and references are listed in the following subsections at the end of the discussion on each geophysical method.

## 8.4.2 Geophysical Methods

### 8.4.2.1 Electromagnetics

The electromagnetic (EM) method provides a means of measuring the electrical conductivity of subsurface soil, rock, and groundwater. Electrical conductivity is a function of the type of soil and rock, its porosity, its permeability, and the fluid composition and saturation. In most cases the conductivity of the pore fluids will be responsible for the measurement. Accordingly, the EM method applies both to assessment of natural geohydrologic conditions and to mapping of many types of contaminant plumes. In addition, trench boundaries, buried wastes, drums, and utility lines can be located with EM techniques.

#### 8.4.2.1.1 Applicability

Although EM is not a definitive technique, it is useful for several reasons. First, an EM survey can be conducted over an entire site very quickly. In addition, EM methods are generally inexpensive, even for coverage of large areas. Often, 100 acres or more may be surveyed in just a few days time (depending on desired detail). More importantly, EM data can be used to direct the more expensive phases of an investigative project, potentially resulting in a large cost savings. For example, rather than drilling several dozen monitoring wells while searching for groundwater contamination, an EM conductivity unit may be used to survey for a conductive (or resistive) plume. Several EM survey lines may be run to provide definition of the plume and an indication of its source area, reducing the number of exploratory wells required. This approach could potentially result in better well placement at a significant cost savings. Another reason why EM should be considered is to fill in data gaps and to reduce the risk of missing a facet of the investigation, such as the presence of previously undetected refuse trenches, buried drums, or changing hydrologic conditions.

Electromagnetic methods may be used in many situations for a variety of purposes. The following list includes major uses related to investigations of hazardous waste sites:

- Defining the location of a contaminant plume (This could lead to the identification of downgradient receptors, source areas, and flow directions if the conductivity of the plume (target) is distinct in comparison to the host (background) hydrogeologic setting.)
- Locating buried metal objects (e.g., drums, tanks, pipelines, cables, monitoring wells)
- Addressing the presence or location of bedrock fault / fracture systems (This is important for identification of preferential pathways of water flow in bedrock.)
- Mapping grain size distributions in unconsolidated sediments
- Mapping buried trenches
- Defining lithological (unit) boundaries
- Determining the rate of plume movement by conducting multiple surveys over time

The above list is only partial; in fact, EM methods may be used wherever a significant change in conductance can be measured. EM theory will be discussed later; however, in general, EM should be considered for use when any suspected target is anticipated to have a conductivity significantly different from background values. Factors such as cost, site-specific conditions, and equipment availability should also be evaluated before deciding to proceed with an EM survey.

### 8.4.2.1.2 Procedures

#### A. Objectives

The reader should evaluate the objectives of hazardous waste site investigations in light of EM geophysical capabilities. If the purpose of the site study is simply to confirm the presence of contaminants with minimal effort, EM methods may provide too much detail and no direct evidence; direct methods, such as installing a few wells or limited sampling, may be more suitable. If a site is to be characterized in detail and if assessment of geohydrologic conditions and identification of all source areas, plumes, and receptors are a priority, then EM (and other geophysical methods) may be a cost-effective way of selecting strategic locations for monitoring wells, directing test pit operations, efficiently selecting sampling points, and providing information between site sampling points.

#### B. Existing Data

If EM equipment is identified as theoretically capable of providing the type of information desired, the user should further evaluate the equipment to determine whether it is appropriate for use under the conditions found at a particular site. Evaluation of existing data can identify problems that may be encountered in the field:

- Variations in geohydrologic conditions (e.g., varied water table conditions or changes in rock or sediment) can result in a conductivity range that envelopes the response of the target (e.g., plume) and effectively masks or blocks out any signals.

- Scattered, near-surface metal may mask buried targets such as drums or trenches.

- Near-surface layers of extreme conductivity (high or low) such as a clay lense or surficial frost zone may mask the signal from a deeper target.

An analysis of the site history might more closely define a survey area, thereby cutting survey costs by reducing the size of the survey. Deep targets may be out of the penetration range of many EM units, and specialized equipment may be required. It may be difficult for many EM systems to detect a groundwater contaminant plume through 100 feet of unsaturated over burden. A site reconnaissance should be conducted to identify any other site conditions that may affect the data. Drastic topography changes can affect the quality of EM data obtained with some systems, and this possibility should be considered at each site.

### 8.4.2.1.3 Survey Design

Once the EM survey objectives have been clearly defined, the existing information has been reviewed, and reconnaissance of the site has been conducted, attention should be given to the design of the geophysical survey. The detail required of an EM survey is a primary factor in designing and planning fieldwork. If the purpose of performing EM work onsite is to define a large geologic feature, then a grid using a wide (100- to 1,000-foot) line spacing may be needed. Some instruments are capable of providing a continuous data profile, which makes them less likely to miss small conductors than the typical discrete measurement EM instruments. The importance of designing and implementing a grid system tied into existing "permanent" features (such as roads and buildings) cannot be overstated. This permanent feature will allow the grid to be reoccupied in the field to place drill holes and monitoring wells. Furthermore, additional surveys may be conducted on the site using other geophysical techniques or the same technique to provide an indication of plume movement. These surveys will help in orienting maps and diagrams that are produced later and in defining targets.

For most detailed enforcement-related efforts, a 98 to 100 percent confidence interval should be maintained. For example, if the target area is only 1 percent of the total survey area, then 130 readings would be required for the 98 percent confidence interval. For an accurate definition of an EM anomaly profile (useful in interpretation), four or more anomalous readings are recommended.

### A. Background Noise

Background noise can be a significant factor in the success of an EM survey. Evaluation of existing data and a site reconnaissance will help to identify the probable background noise level. A high noise level can make interpretation difficult and may actually cause an anomaly to be overlooked. It would be practically impossible to delineate a slightly conductive contaminant plume contained in overburden that has a wide natural variation in conductivity. Noise sources can be divided into two groups: (1) natural, such as changing grain size distributions, steeply dipping strata, undetected mafic dikes, drastic topography, unexpected fault zones; and (2) cultural, such as powerlines, houses, railroads, surface metal debris, cars, and radio transmission towers. Some instruments are more sensitive to certain types of noise sources than others. Because there is little published information on this subject, experience is important.

### B. Limitations

All EM instruments have varying limitations with regard to sensitivity and penetration. Published references, operator's manuals, and field experience should be used to evaluate instrumentation versus capability. Exhibit 8.4-1 lists several commercially available instruments along with factors that control their productivity.

Some systems are designed for one operator, some for two operators, and some are flexible and allow one or two operators. Generally, EM coverage for 50-foot readings range from 8,000 line feet per day to 22,000 line feet per day in average terrain. Some instruments are more suited to rugged terrain (steep hills, thick woods, brush, swamps) than others because of equipment configuration. When definition of deep bedrock features is the primary objective of a survey, large equipment along used brush-cut lines (typical in mineral exploration) may be needed. (Note: Productivity will be greatly diminished with higher levels of protection; the productivity factors shown are for unencumbered, unprotected workers in a "clean" area.)

### C. Instrumentation

The following matrix (Exhibit 8.4-2) provides guidance for EM equipment selection. These instruments may or may not be suitable to specific site conditions and investigation objectives; a full discussion of factors affecting their suitability is beyond the scope of this compendium. In addition, a combination of instruments is commonly used to assess site conditions. This discussion includes only some of the currently common instrumentation owned by hazardous waste investigative agencies.

Electromagnetic techniques have also been adapted for downhole applications. These techniques can be useful in defining the vertical extent of a contaminant zone. Some systems work inside polyvinyl chloride (PVC) or Teflon monitoring well casings. For further information on airborne, borehole, or surface EM instruments, the reader should consult the subsections on theory and interpretation and the manufacturer references shown later in this compendium.

Exhibit 8.4-3 compares some of the more common EM systems. The CEM and Max Min II systems are not commonly used for hazardous waste site investigations (they are more commonly used in minerals exploration), but the systems are included for comparative purposes.

**Exhibit 8.4-1**

## FACTORS CONTROLLING PRODUCTIVITY OF SOME COMMON EM UNITS

| Instrument | Manufacturer | No. Operators | Typical Daily Line Miles (50-ft readings) | Notes |
|---|---|---|---|---|
| EM-16-R | Geonics | 2 | 2 | 2 |
| EM-16 | Geonics | 1 | 3-4 | 2 |
| EM-31-D | Geonics | 1 or 2 | 3 | 2 |
| EM-34-3 | Geonics | 2 | 2 | 2 |
| VLF-3 | Scintrex | 1 | 3 | 2 |
| GENIE (SE-88) | Scintrex | 2 | N/A | 1 |
| RADEM-VLF | Crone | 1 | 3-4 | 2 |
| CEM | Crone | 2 | 2 | 1 |
| Max Min II | Apex | 2 | 3 | 1 |
| EM-38 | Geonics | 1 | 3 | 2 |
| EM-33 | Geonics | N/A | 100+ | 1 (for helicopter use) |

---

NOTES: (1) Primarily useful for geological features only.
(2) Useful for geological and cultural features.

Designation such as EM-16 or EM-31 are the manufacturer's model numbers and do not imply equipment complexity or capability.

### 8.4.2.2 Electrical Resistivity

Electrical resistivity surveys provide information about the subsurface distribution of the ground resistivity. The information can be used to infer groundwater quality and lithologic and geologic information. Both horizontal and vertical changes in ground resistivity can be mapped by resistivity surveys. In practice, resistivity surveys are mostly used to determine the vertical resistivity changes. Lateral resistivity changes are more easily mapped by electromagnetic surveys. Often, electromagnetic and resistivity surveys are used together.

#### 8.4.2.2.1 Applicability

Electrical resistivity (ER) data are subject to interpretation; therefore, ER field results should be checked periodically and confirmed by direct methods, such as sampling or drilling. This type of confirmation is essential in enforcement cases.

Although ER is not a definitive technique, the data are useful for several reasons. Typical productivity with conventional resistivity equipment is several thousand line-feet per day (similar to seismic refraction work, but much less than electromagnetics - two competing techniques). This high productivity rate allows a large amount of useful data to be collected in a relatively short period of time. For example, rather than drilling several dozen monitoring wells or test borings to develop a complete picture of the site stratigraphy and structure, a few wells can be drilled (for control) and information about the rest of the site can be obtained by using resistivity methods. Method integration such as this can reduce the amount of time and the costs required for a project. If the investigative objective is to locate a groundwater contaminant plume, then resistivity techniques could be used to define the plume, its probable receptors, and its source area. Once the plume has been defined, a few confirmation monitoring wells are required. Using resistivity techniques could result in better well placement. Using ER data can also add another dimension to the investigative effort and data, which could fill in data gaps and could possibly reduce the risk of missing a facet of the investigation, such as the presence of a previously undetected contaminant plume or bedrock valley (as depicted in Exhibit 8.4-4).

Resistivity methods may be used in a wide array of situations and for a variety of purposes. The following is a partial list of major uses related to investigations of hazardous waste sites:

- Definition of a contaminant plume (This could lead to the identification of downgradient receptors and source areas.)
- Waste pit delineation
- Definition of bedrock fault / fracture systems
- Water table mapping (for contour maps)
- Stratigraphic mapping of soil layers (particularly useful in overburden, discriminating clays from sands and establishing their thicknesses)
- Defining bedrock topography (valleys)

Resistivity methods may be used whenever the feature to be mapped has a contrasting resistivity with the background material.

## Exhibit 8.4-2
## APPLICATION GUIDELINES FOR EQUIPMENT USE

| Equipment Use | EM-16 | EM-16R | EM-31 | EM-34 |
|---|---|---|---|---|
| Locate single shallow buried drum | 3 | 3 | 1 | 3 |
| Locate many shallow buried drums | 2 | 3 | 1 | 2 |
| Locate single deep buried drum | 3 | 3 | 3 | 3 |
| Locate many deep buried drums | 2 | 3 | 2 | 2 |
| Define shallow fault zone | 1 | 2 | 2 | 2 |
| Define deep fault zone | 1 | 3 | 3 | 2 |
| Delineate shallow contaminant plume | 3 | 1 | 1 | 1 |
| Delineate deep contaminant plume | 3 | 1 | 2 | 1 |
| Locate shallow pipeline | 1 | 3 | 1 | 2 |

---

1. Good success rate
2. Moderate success rate
3. Poor success rate--not applicable

shallow is only several meters

deep is several tens of meters

NOTE: This table is based primarily on field experience. Designations such as EM-16 or EM-31 are the manufacturer's model numbers and do not imply equipment complexity or capability.

## Exhibit 8.4-3
## COMPARISON OF COMMON EM SYSTEMS

| | VLF-3 EM-16 | EM-16R | EM-31 | EM-34 | EM-38 | CEM | Max Min II |
|---|---|---|---|---|---|---|---|
| Operators | 1 | 1 or 2 | 1 or 2 | 2 | 1 | 2 | 2 |
| Typical in saturated sands (meters) | 20-30 | 20-30 | less than 5 | see below | less than 2 | see below | see below |
| Source (Tx) | Navigational signals continuously broadcast by U.S. Navy | | self-contained coil | self-contained coil | self-contained coil | 2 self-contained coils | self-contained coil |
| Receiver (Rx) | Entire unit is Rx (2-antennae) | | self-contained coil | self-contained coil | self-contained coil | 2 self-contained coils | self-contained coil |
| Frequency | Interchangeable Rx crystals 15-25 kHz | | 9.8 kHz | 10 meter 6.4 kHz<br>20 meter 1.6 kHz<br>40 meter 0.4 kHz | 13.2 kHz | 390 Hz<br>1830 Hz | variable<br>222 Hz<br>888 Hz<br>1222 Hz |
| Tx-Rx spacing | Unlimited | | 3.6 meters | 10, 20, 40 meters | 1 meter | 100,200,400 feet | 100, 200, 400, 800 feet |
| Notes | Receives only specified frequencies. Will not read most noise. Penetration depends on formation resistivity. Maximum penetration is over 100 meters. | | Continuous reading with a strip chart recorder. Can be used as a horizontal or vertical dipole for control of penetration. | Penetration varies with coil separation and with orientation. Maximum penetration is 50 meters. | Lightweight | Can take vertical and horizontal readings. Each coil is used as a source and then a receiver (shootback). Maximum penetration is approximately 50 meters. | Survey corrections are applied for topography while reading is being taken. Maximum penetration is approximately 100 meters. |

Electrical resistivity surveys involve the use of metal electrodes that are driven into the ground and long cables that drag along the ground. Set-up time can be long if the electrode spacing is large. Special handling and decontamination procedures will be required at hazardous waste sites.

#### 8.4.2.2.2 Procedures

Electrodes are typically arranged in one of several patterns, called electrode arrays, depending on the desired information. Electrical resistivity techniques can determine the vertical subsurface resistivity distribution beneath a point. In this type of survey, called vertical electrical soundings, the electrode array is expanded systematically and symmetrically about a point. For each set of electrode spacings, apparent resistivity is determined from measurements of potential and input current. The resultant plot of apparent resistivity versus electrode spacing is interpreted to provide the subsurface resistivity with depth distribution at that one particular point. Examples of three common arrays are given in Exhibit 8.4-5. The Wenner and Schlumberger arrays are somewhat more common than the Dipole-Dipole and other arrays. These arrays (Wenner, Schlumberger) start with a small electrode spacing that is increased to permit deeper penetration for sounding.

The manner in which the apparent resistivity changes with the electrode separation can be used to determine formation conductivity and layer thickness. To increase accuracy, the user should evaluate the interpretation of resistivity data against the existing subsurface information. With any set of apparent resistivity reading, a number of solutions are possible, so existing data must be used to select the one that fits best. A formation resistivity may be assigned, but without geological control the material is not known. Resistivity electrode arrays can also be used with constant inner-electrode spacing and to develop a lateral picture of the site through profiles. Stratigraphic control is even more important when mapping lateral changes with constant electrode spacings, because layer thickness changes alone can cause changes in apparent resistivity. The desired resolution is a major factor in deciding how closely to space measurements for a given survey.

In practical application, a resistivity survey target (such as a plume or clay lens) should have a resistivity contrast (positive or negative) over 20 percent from background. This change in resistivity should be 50 percent or more to provide proper detection and delineation. For example, if a resistivity survey were being conducted to delineate a groundwater contaminant plume (in overburden) with a resistivity of 200 ohm meters, a background-saturated over burden resistivity of over 400 ohm meters (for a conductive plume) or under 100 ohm meters (for a resistive plume) would probably by detected, providing other factors (such as depth) are not detrimental.

When depth sounding, resolution of individual layers has an accuracy generally around 20 percent; accuracy can be substantially more or less depending on the site conditions and operator expertise. Vertical resistivity sounding is usually less accurate than seismic refraction work, which is often conducted within a 10 percent error tolerance. However, geologic units may be distinguishable (by geophysics) only with the use of resistivity methods at some site.

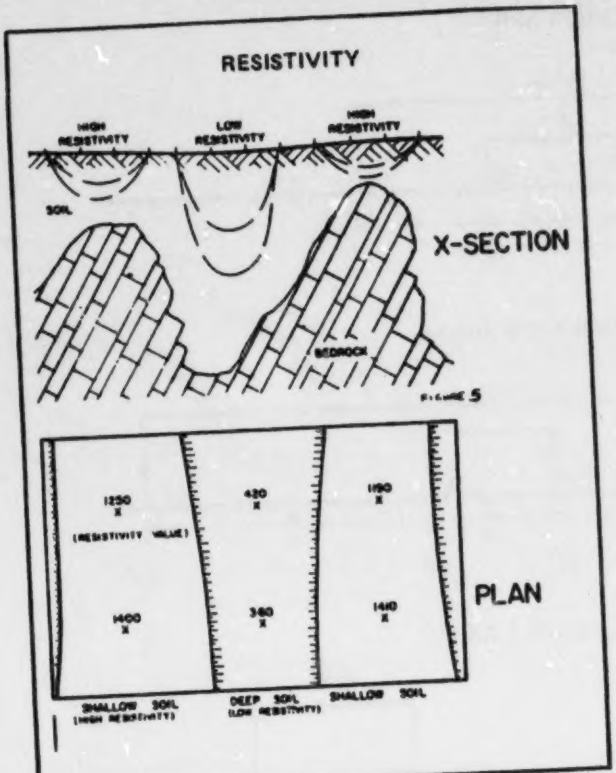
#### 8.4.2.2.3 Survey Design

Data can be collected at randomly located stations or along survey lines. If vertical electrical soundings are performed to obtain resistivity changes with depth, then the soundings are positioned where the information is most useful. If measurements are made to map lateral resistivity changes, then the survey is best performed on a grid or on survey lines. The station spacing will be determined from the target size.

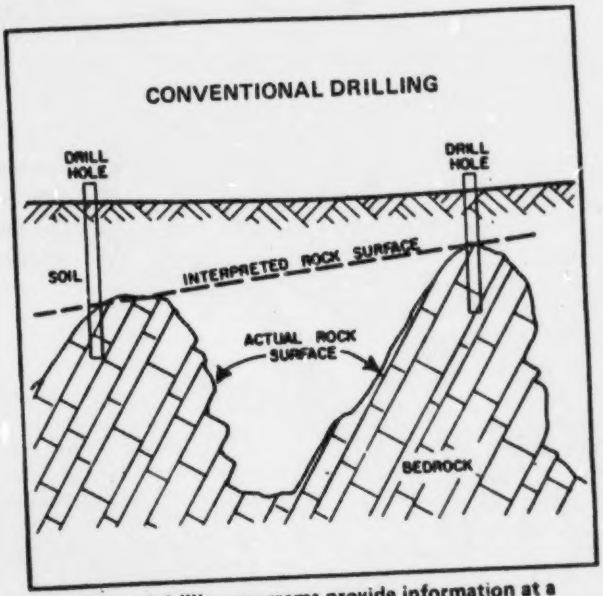
##### A. Background Noise

Evaluation of existing data and a site reconnaissance will help to identify the possible background noise level. A high noise level can make interpretation difficult and may actually mask

## Exhibit 8.4-4
## POTENTIAL EFFECTIVENESS OF RESISTIVITY VS. DRILLING


RESISTIVITY
HIGH RESISTIVITY
LOW RESISTIVITY
HIGH RESISTIVITY
SOIL
X-SECTION
BEDROCK
FIGURE 5
1250 x
(RESISTIVITY VALUE)
420 x
1190 x
PLAN
1400 x
380 x
1410 x
SHALLOW SOIL (HIGH RESISTIVITY)
DEEP SOIL (LOW RESISTIVITY)
SHALLOW SOIL

Resistivity measurements in an area with a variable bedrock surface can give qualitative depth information and can be used to define problematic zones.

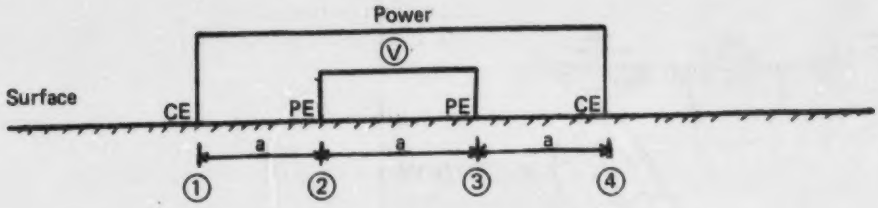

CONVENTIONAL DRILLING
DRILL HOLE
DRILL HOLE
SOIL
INTERPRETED ROCK SURFACE
ACTUAL ROCK SURFACE
BEDROCK

Conventional drilling programs provide information at a single point only. Information between drill holes is missing and can lead to serious, sometimes critical, interpretation errors.

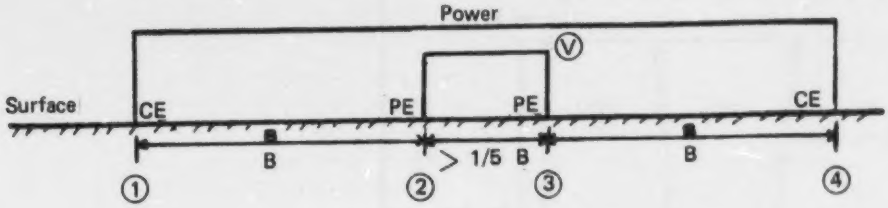
SOURCE: J. R. Peffer and P. G. Robelen, Affordable: Overburden Mapping Using New Geophysical Techniques, 1983.

## Exhibit 8.4-5
## EXAMPLES OF COMMON ER ARRAYS

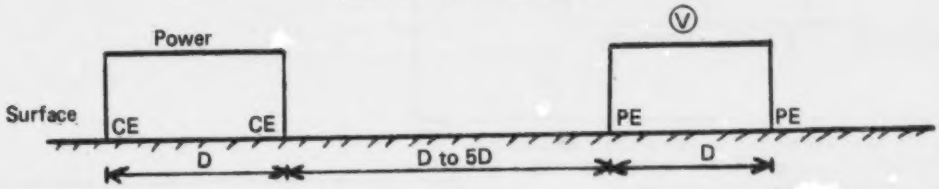
### WENNER ARRAY


Power
Ⓥ
Surface
CE
PE
PE
CE
a
a
a
①
②
③
④

### SCHLUMBERGER ARRAY


Power
Ⓥ
Surface
CE
PE
PE
CE
B
> 1/5 B
B
①
②
③
④

### DIPOLE-DIPOLE ARRAY


Ⓥ
Power
Surface
CE
CE
PE
PE
D
D to 5D
D

① Electode Number
PE Potential Electrode
CE Current Electrode
Ⓥ Voltmeter

**SOURCE:** Based in part on W. M. Telford et al., Applied Geophysics, 1976, and R. E. Sheriff, Encyclopedic Dictionary of Exploration Geophysics, 1984.

an anomaly. It would be practically impossible to delineate a slightly conductive contaminant plume contained in overburden that has wide natural variation in conductivity. Noise sources can be divided into two groups: natural, such as discontinuous clay layers, undetected mafic dikes, drastic topography, unexpected fault zones, variable water table, and lightning; and cultural, such as powerlines, railroad tracks, and radio transmission towers. Some instruments are more sensitive to certain types of noise sources than others. Since there is little published information on instrument noise sensitivity, experience is important.

### B. Depth of Investigation

As a rule of thumb when lateral resistivity is being conducted, the array should be four or five times the distance from the ground surface down to the desired target. For vertical sounding, this suggested spacing should be about ten times the anticipated target depth. These suggestions should be used only as general guidance.

## 8.4.2.2.4 Miscellaneous Considerations

### A. Instrumentation

For most shallow work at hazardous waste sites, practically any resistivity system will suffice. Generally, equipment capability becomes important only when the desired investigative depth exceeds 70 to 100 feet. Larger power sources are needed to provide a measurable electrical potential with a wider electrode spacing. Some newer resistivity units are capable of electronic data storage, and other features. Often, the peripheral capabilities of an ER system may be the deciding factor when purchases are considered.

Borehole resistivity equipment has been used (in uncased boreholes) to determine relative formation porosity and other factors. For more information on this equipment, the reader should refer to the borehole geophysics subsection of this compendium.

### B. Calibration

ER equipment requires calibration, either in the field or in the laboratory; dated records of this calibration should be kept in the equipment management file and in the appropriate project file. Calibration is used to establish the reliability and accuracy of the equipment; calibration typically includes an internal circuit check or actual field trials (e.g., tests over a known target). Equipment that historically exhibits fluctuations in calibration should not be used. The equipment serial number should be recorded on the calibration records. If the manufacturer recalls equipment, this fact should be explained and documented for instrument maintenance in the proper file. The current source and potentiometer must be calibrated on any type of resistivity equipment. The instrument's current source may be calibrated by placing a reference ammeter in series with the electrode cables. The reading obtained on the reference ammeter is compared with the value read from the instrument's current source ammeter. The current source ammeter is then adjusted accordingly.

The potentiometer is calibrated by either of two methods. The preferred field method, which is similar to the calibration of the current source, is done by comparing the instrument's indicated potential to that potential measured with an independent voltmeter. An alternative means of calibration, which can be performed in the laboratory, involves placing a precision resistor of a known value in series with the current load. A potentiometer is then placed across the resistor. The potential measured should be equal to the product of the known resistance and indicated current.

### C. Data Reduction

The raw data are the measured potential produced by a known current. To calculate the $rho_{app}$ (apparent resistivity), these above known quantities are used. (See Exhibit 8.4-5, Common ER Arrays.) The electrode configuration is also used in the determination of apparent resistivity, which is defined by:

$$rho_{app} = (2 \times \pi \times V/I) / (1/r_1 - 1/r_2 - 1/R_1 + 1/R_2)$$

where:

$V$ = The circuit potential (voltage)
$I$ = Applied current (amperage)
$r_1$ = Distance between electrode #1 and #2 (meters)
$r_2$ = Distance between electrode #3 and #4 (meters)
$R_1$ = Distance between electrode #1 and #3 (meters)
$R_2$ = Distance between electrode #3 and #4 (meters)
$rho_{app}$ = Apparent resistivity

Apparent resistivity is the resistivity measured at the ground surface and usually has units of ohmmeters or ohmfeet. The apparent resistivity is a function of the distribution of actual ground resistivities and the electrode geometry. Interpretation and reduction of the resistivity sounding are beyond the scope of this compendium; interpretation and reduction often involve curve matching or computer analysis. For further information, the reader should refer to the references listed in Appendix 8.4B, particularly Zohdy (1975).

## 8.4.2.3 Seismic Methods Applicable to Hazardous Waste Site Characterization

Seismic techniques have been useful in some instances for assessing subsurface geohydrologic conditions such as depth to bedrock; depth, thickness, dip, and density of lithologic units; horizontal and vertical extent of anomalous geologic features (folds, faults, and fractures); the approximate depth to the water table; and, in conjunction with geophysical well log data, the porosity and permeability of lithologic units. Seismic techniques have also been used to delineate the boundaries of subsurface bulk waste trenches and the depth of landfills.

### 8.4.2.3.1 Applicability

**Seismic Refraction and Reflection Techniques**

The method of seismic refraction consists of measuring the travel times of compressional waves that are generated by a surface source and that are critically refracted from subsurface refraction interfaces and received by surface receivers. First-arrival travel times of seismic energy plotted against source-to-receiver distance on a time-distance curve are characteristic of the material through which they travel. The number of line segments on the time-distance plot indicates the number of layers. The inverse slope of the line segments indicates the velocities of the layers.

The method of seismic reflection consists of measuring the two-way travel times of compressional waves that are generated by a surface source and that are reflected from subsurface reflecting interfaces. Depths to each reflecting interface can be deduced from reflection two-way travel times integrated with layered velocity information.

Higher subsurface resolution of shallower layers is possible with shallow reflection techniques. Modern multichannel engineering seismographs have digital filtering capabilities that allow later arriving wide-angle reflections to be detected from earlier refraction arrivals.

Seismic velocities obtained from a refraction survey over an area do not always agree with those obtained from a reflection survey over the same area. This variance may be because refraction velocities are obtained from rays traveling parallel to the top of a layer, whereas, reflection velocities are obtained from waves traveling perpendicular to the strata at the bottom of a layer.

The technique of seismic refraction has been used to a greater extent than seismic reflection in the subsurface characterization of hazardous waste sites.

### 8.4.2.3.2 Procedures

**Preliminary Considerations**

The planning, selection, and implementation of a shallow seismic survey require careful consideration by qualified, experienced personnel. At a minimum, the following steps are required:

- 1. Review existing site, area, and regional subsurface geologic and hydrogeologic information including physical and chemical soil characteristics.
- 2. Define known hazards posing a threat to the safety of personnel who are conducting the seismic survey and topographic survey.
- 3. Define the purpose of the subsurface investigation.
- 4. Choose the appropriate seismic method to be conducted.
- 5. Define anticipated survey area from either USGS 7.5-minute quadrangle maps or published base maps of the particular site.
- 6. Add survey coordinates and elevations of all shot and geophone locations to be used before the actual survey. Static elevations corrections are applied later to raw seismic data to compensate for travel time differences because of elevation changes along seismic lines.

**Survey Design**

A. Seismic Refraction

The length of a seismic refraction line must be at least four times the maximum penetration depth desired. This length will ensure that head-wave energy will be received from refractors down to the maximum penetration depth. The spacing between individual geophones controls the degree of resolution available, and a spacing of 3 to 15 meters is commonly used. Closer spacings may be used for very shallow, high-resolution profiles. Long seismic lines are shot using the method of continuous in-line reversed refraction profiling, whereby the entire seismic line is shot in segments. Shot points are located at each end of and at intermediate points along each spread segment. The end shot point of each spread segment coincides with an end or intermediate position shot point of the succeeding spread segment. After a spread segment is shot, the geophone spread is moved to the next succeeding spread segment. The procedure is repeated until the complete reversed seismic refraction profile along the line has been developed.

### B. Seismic Reflection

The major application of seismic reflection is in the mapping of the overburden bedrock interface where over burden thickness exceeds 30 meters. Reflections from the overburden-bedrock interface show up prominently on seismograms where large contrasts between acoustic layer velocities exist. To minimize the effect of low-frequency refraction arrivals, the investigator should use geophones with natural frequencies higher than those used in refraction work. Filtering capability and amplifier gain control of modern seismic data acquisition units allow these reflection events to be enhanced, making it possible for a high degree of accuracy when mapping bedrock attitude.

Exhibit 8.4-6 represents the time-distance curve for bedrock at a depth of 90 meters with a $P$-wave velocity of 5 km/sec overlain by an overburden layer with a $P$-wave velocity of 1.5 km/sec. The dark ground roll area on the curve is an area of shot-generated surface-wave energy that travels along the surface of the ground and tends to mask reflection events. The amplitude distance curve for rays reflected from the bottom of the overburden layer (Exhibit 8.4-6) increases at critical distances for $P$- and $S$-waves and remains uniform at small source-to-receiver distances.

At wide angles of incidence, or large source-to-geophone distances, reflection events are subject to interference effects from earlier arriving refracted events. To eliminate interference effects caused by ground roll and earlier refraction arrivals, it is desirable to obtain an optimum shot to first geophone distance at which to place geophones in shallow reflection work. This optimum "window" is empirically developed in the field by observing seismograms recorded at different shot-to-first-receiver distances. The optimum window for recording reflections from bedrock at a depth of 90 meters is shown in Exhibit 8.4-6. This window is at a shot-to-receiver distance range over which the reflected $P$-wave amplitude remains relatively uniform.

Part A of Exhibit 8.4-7 is a seismic record that was recorded on a portable 12-channel signal-enhancement seismic data-acquisition unit with digital filtering capability. Drill logs from the area over which the record was obtained indicate that bedrock is at a depth of 91 meters and is overlain by glacial till and a surface layer of silt. The selected distance of optimum source to first geophone was 22.9 meters with a geophone spacing of 7.6 meters. Two hammer blows were necessary to enhance the record, and no digital filtering was applied. The direct $P$-wave through the over burden layer is clearly visible as a first break on each trace. The reflected $P$-wave from the base of the overburden layer is clearly visible in the 120 to 130 millisecond range. The first trace from a geophone 22.9 meters away from the source illustrates masking effects caused by ground roll. The actual shot-to-first-receiver distance should be increased slightly to obtain optimum representation of the reflected event. Part B of Exhibit 8.4-7 is a seismic record obtained from virtually the same location as in A, but low-cut digital filtering has been applied to further enhance the data.

The next step in this procedure is to move the shot point and geophone spread along a line and repeat the procedure. This step allows for multiple coverage and is known as common-depth-point (CDP) profiling.

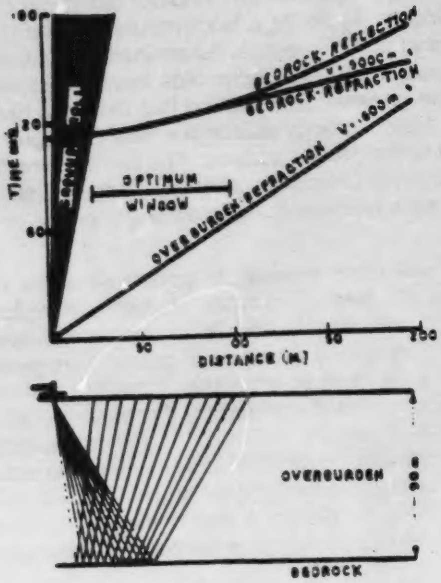
### 8.4.2.3.3 Miscellaneous Considerations

### A. Instrumentation

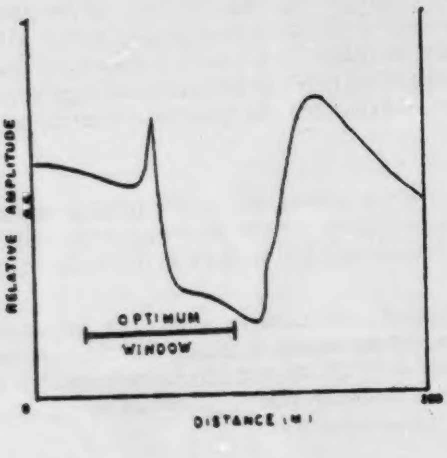
Shallow seismic surveys conducted at hazardous waste sites generally do not require large energy sources and can be either mechanical or explosive in nature.

## Exhibit 8.4-6
## TIME-DISTANCE AND AMPLITUDE-DISTANCE CURVES

A.



B.



**SOURCE:** J. A. Hunter (1982).

Mechanical and contained explosive sources are used in populated areas or when desired penetration depths are less than 100 to 300 feet. Hammer surveys are conducted by striking a steel plate coupled to the ground with a sledge hammer. An inertial switch on the hammer is connected to the seismic data acquisition system with a cable, enabling the moment of hammer impact to be accurately recorded. Another technique commonly used is the weight drop or "thumper" technique. Typically, a truck-mounted 3-ton weight is dropped from a height of 10 feet. The instant of group impact is determined by a sensor on the weight. A seismic energy source developed by EG&G Geometrics involves an air-powered piston striking a steel plate coupled to the ground. This method has the trade name Dynasource. The Betsy seisgun is a weak mechanical energy source in which a shotgun shell is detonated inside a chamber that is coupled to the ground surface. The Dinoseis method uses a confined chemical explosion in a truck-mounted explosion chamber to drive a steel plate against the bottom of the chamber, transmitting a pressure pulse into the ground.

Explosive sources are used sparsely in populated areas or when penetration depths are greater than 100 to 300 feet. Two types of chemical explosives, gelatin dynamite and ammonium nitrate, are commonly used in explosion surveys and are detonated in seated boreholes. Gelatin dynamite is a mixture of gelatin, nitroglycerin, and an inert binder material that can be used to vary the strength of the explosion. Ammonium nitrate is a fertilizer that is mixed with diesel fuel and is detonated by the explosion of a primer. A charge of about 1 pound of explosives is usually sufficient to obtain penetration depths ranging from approximately 100 to 300 feet. Explosive sources generate wave fronts that are very steep and show up as distinct arrivals on seismograms. These sharp pulses, however, are more likely to cause damage to nearby structures. It may not be advisable to use explosive sources at hazardous waste sites where unknown gases or buried containers may be present.

A complete seismic recording system or seismograph detects, records, and displays ground motion caused by the passage of a seismic wave. A geophone (Exhibit 8.4-8) is commonly a moving-coil electro-mechanical transducer that detects ground motion. The moving coil is free to move in the annular gap between the poles of the permanent magnet, creating an output voltage that is proportional to the actual ground motion or to the motion of the outer geophone case. At frequencies below the resonant frequency of the coil or outer case suspension, the coil and outer case move together and output voltage falls off rapidly. The selected resonance frequency or natural frequency of a geophone must be below that of the lowermost frequency anticipated.

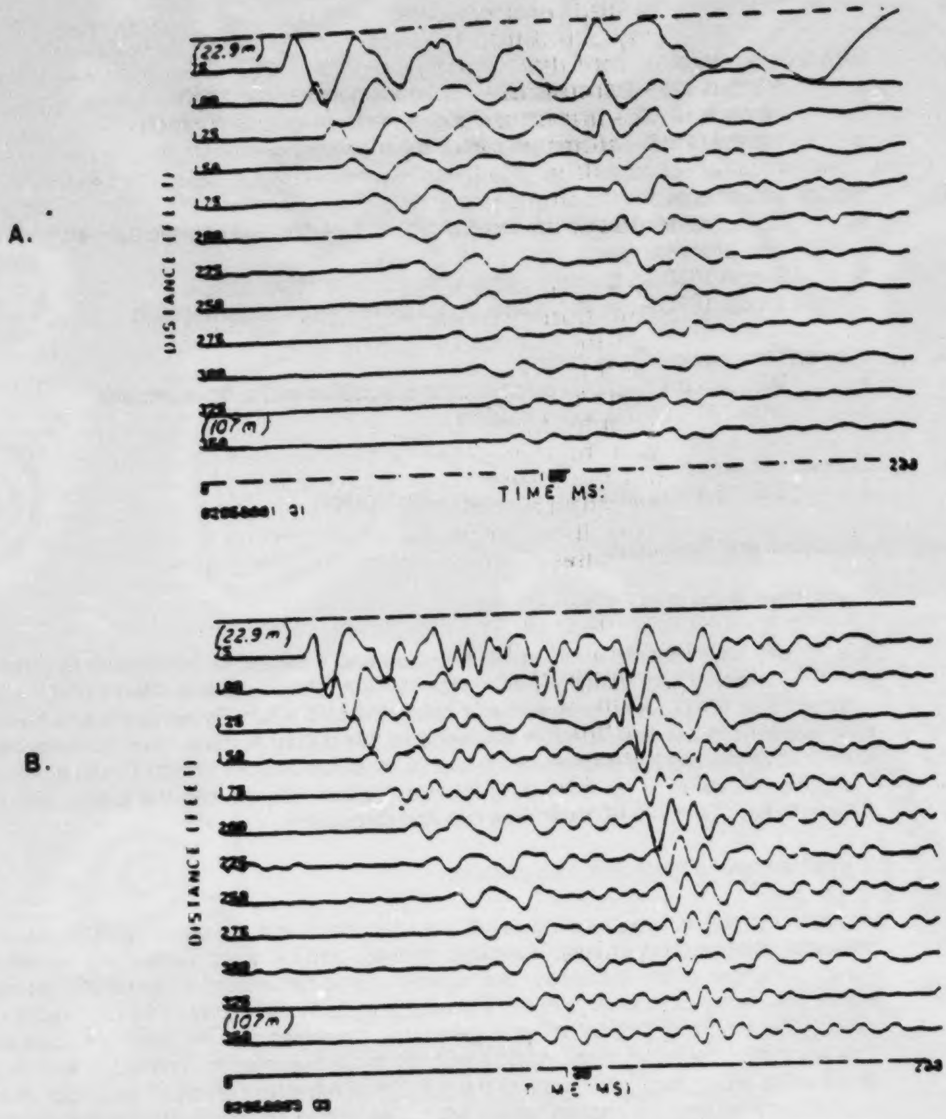
Each geophone detects ground motion at a point on the surface and passes this information through a single recording channel as a frequency modulated signal. This signal is transformed into the time domain and appears as one trace on the resulting seismogram.

Single-channel systems are used in small-scale engineering surveys, and the source and receiver are successively moved to create the characteristic travel-time curve. Multichannel systems consisting of 12, 24, 48, and 96 channels are in more common use today. These systems are capable of recording energy generated by a single source that is detected by a series of geophones at various distances.

Seismic recording systems are equipped with amplifiers that have individual gain controls, which are set as high as possible, and with digital filters that exclude frequencies outside the useful signal range between 20 and 200 Hz. A galvanometer converts the current generated by the output voltage from each geophone into the time domain. This information is then recorded onto ultraviolet sensitive paper for analysis.

Most seismic data-acquisition systems in use today have the ability to sort and sum waveforms from repeated shots at the same shot point. This feature is known as signal enhancement and

## Exhibit 8.4-7
## SEISMIC RECORDS



SOURCE: J. A. Hunter (1982).

is desirable because it serves to cancel out much of the systematic shot-generated and random background noise from the characteristic waveform. This method is also known as stacking of the individual wave traces. The following are some of the more common seismic data-acquisition units in use today:

1. EG&G Geometrics
   - a. Nimbus 125 – 2-channel signal-enhancement seismograph
   - b. Nimbus 1210F – 12-channel signal-enhancement seismograph
   - c. Nimbus 2415 – 24-channel signal-enhancement seismograph

2. BISON Instruments, Inc.
   - a. "Geo Pro" Models 8012A and 8024-12 and 24-channel seismic data-acquisition and processing unit
   - b. Model 1580 – 6-channel signal-enhancement seismograph
   - c. Model 157C – single-channel signal-enhancement seismograph

3. Weston Geophysical Corporation
   - a. WesComp 11 – digital seismic data-acquisition and processing unit
   - b. USA 780 – 24-channel amplifiers

4. Dresser Industries
   - a. SIE RS-4 – 12-channel refraction seismograph

## B. Data Interpretation and Reduction

### 1. Corrections Applied to Refraction Data

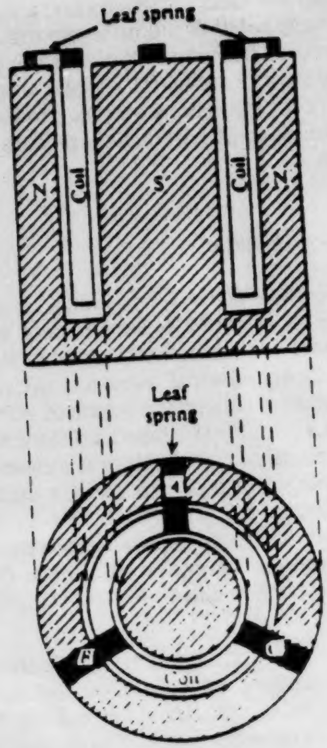
It is usually necessary to apply static elevation and weathering corrections to refraction data to correct for variations in surface receiver elevations and effects of the low-velocity layer (LVZ). A reference datum below the LVZ is usually selected, and travel-time corrections are calculated in reference to this datum surface. This process has the effect of placing the source and group of receivers directly on the datum surface. Various methods exist for correcting for near-surface effects, and the reader should refer to Telford et al., 1976, for a more detailed discussion.

### 2. Errors Inherent to Refraction Interpretation

Errors in refraction interpretation result from incorrect reading of the data, incorrect geologic interpretation of layer velocities derived, and incorrect underlying assumptions. At larger offset distances, the seismic signal decreases in amplitude as the higher frequency components of the signal attenuate more rapidly. The probability of picking the incorrect first arrival at a geophone increases with increasing distances. This error may cause an inappropriate velocity to be assigned to a refractor and may also lead to an erroneous estimate of the number of refractors present. Incorrect intercept times may then be chosen, which will cause wrong estimates of refractor depths and dips.

Seismic velocities that are determined are average values over the entire path traveled by the head-wave. The relationship between the velocity of a refractor and the geology may be complex. Detailed knowledge of the relationship between seismic velocity and lithologic markers, facies boundaries, and geologic time markers are necessary for accurate conclusions to be drawn from a refraction survey.

## Exhibit 8.4-8
## GEOPHONE SCHEMATIC


Leaf spring
N
Coil
S
Coil
N
Leaf spring
Coil

SOURCE: Telford et al., (1976).

The primary assumption made in refraction interpretation is that the seismic velocity of a layer is constant and increases with layer depth. If the velocity of a layer is less than that of the layer immediately overlying it, no head-wave is returned to the surface from the layer, and the layer is not represented on the time-distance curve. Velocity reversals with depth, if undetected, lead to depth estimates that are too deep. If the seismic velocity of a layer varies laterally, dip calculations will be affected. Another assumption is that all velocity layers are recognizable as first arrivals at geophones. This assumption is not always correct, however; some layers may not register as first arrivers. The effect of this condition is opposite to that of a velocity reversal with depth and will lead to depth estimates that are too shallow. Finally, a refractor must be sufficiently thick for it to be detected. These conditions may lead to incorrect paring of segments of the time-distance curve for reversed refraction profiles and may lead to incorrect estimates of refractor dip.

### 3. Corrections Applied to Reflection Data

Static elevation and weathering corrections must be applied to reflection data. These corrections are easier to apply to reflection data because reflection raypaths are primarily vertical as opposed to refraction raypaths. Reflection data must be corrected for normal moveout. Compressional wave energy that is generated from a sur face source and reflected from a subsurface interface arrives at a near-source geophone earlier than it arrives at a geophone located a distance away from the source. This difference in time is the normal moveout. Normal moveout must be removed to enhance primary reflection events. Dip moveout can be calculated from reversed reflection sections and is the quantity $td/\Delta x$ in Exhibit 8.4-9. Migrated reflection sections are those for which we assume that the seismic line is perpendicular to layer dip, the true dip to be calculated from the dip moveout. These corrections are dynamic corrections; more complete discussion can be found in Dobrin, 1960, and Kleyn, 1983.

The main objective in the method of seismic reflection is to detect the reflected P-wave from a background of random ambient noise and systematic shot-generated noise. The higher the signal-to-noise ratio, the more reliable the recording of the arrival time of the reflected phase. In reflection work, only vertical high- frequency geophones are used. These geophones are sensitive to the vertical component of ground motion, which is high for $P$-waves and small for $S$-waves, thus eliminating much of the systematic noise caused by $S$-waves. Shot-generated noise is further reduced through the use of stacking of records from identical subsurface sections. Ambient noise is reduced through the use of seismometer patterns and multicoverage techniques.

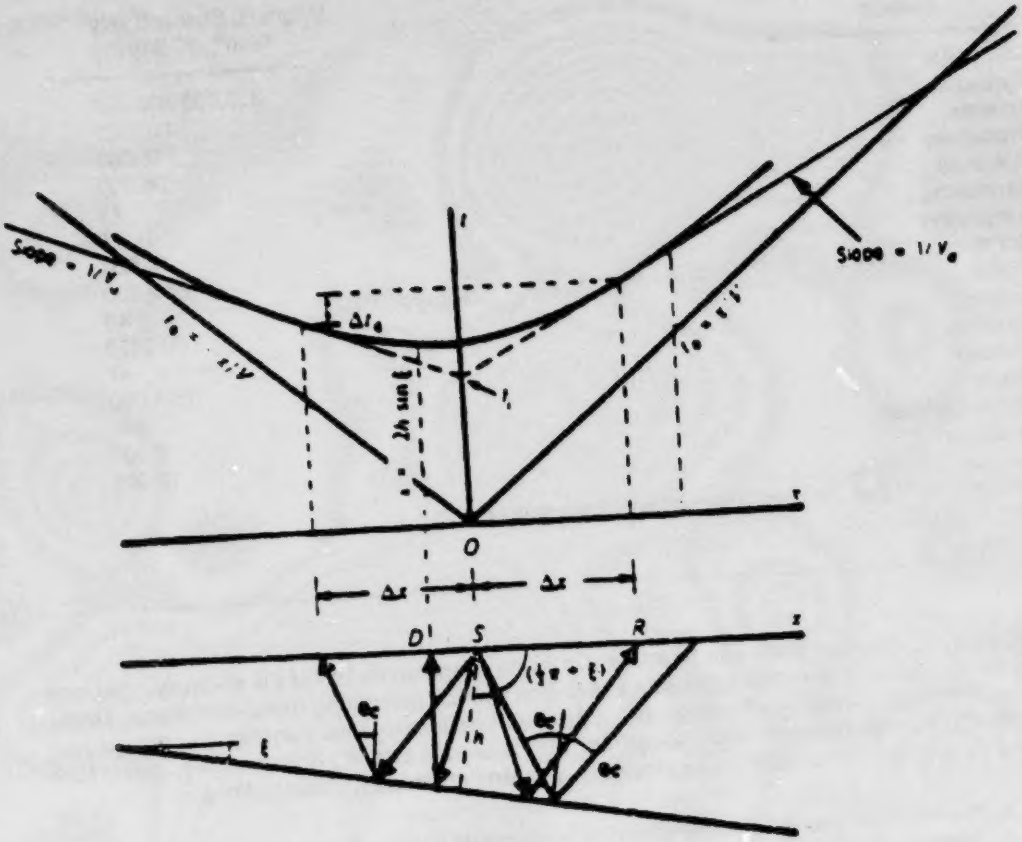
## 8.4.2.4 Magnetics

Magnetometer surveys are used to identify areas of anomalous magnetic field strength. Although natural conditions may cause anomalies, shallow-buried ferrous metal objects (i.e., drums or other waste-related metal) exhibit strong anomalies that are rarely confused with natural sources.

### 8.4.2.4.1 Applicability

The magnetic methods described in this subsection are applicable to locating buried drums and other buried ferrous metal objects; locating waste pits that contain metal; locating underground utilities such as pipelines, cables, tanks and abandoned well casings; clearing drilling sites; and identifying geologic features that exhibit sufficient magnetic contrast.

## Exhibit 8.4-9
## REVERSED REFLECTION PROFILE


t
Slope = 1/V₀
Slope = 1/V₀
Δt₀
t₀ = x/V
t₀ = x/V
2h sin ξ
t₁
x
O
Δx
Δx
D'
S
R
z
(½π + ξ)
θc
θc
θc
h
ξ

## Exhibit 8.4-10

## MAGNETIC SUSCEPTIBILITIES OF ROCK MATERIALS[1]

| Material | Magnetic Susceptibility ($K10^6$, CGS units) |
|---|---|
| Magnetite | 300,000-800,000 |
| Pyrrhotite | 125,000 |
| Ilmenite | 135,000 |
| Franklinite | 36,000 |
| Dolomite | 14 |
| Sandstone | 17 |
| Serpentine | 14,000 |
| Granite | 28-2,700 |
| Diorite | 46 |
| Gabbro | 68-2370 |
| Porphyry | 47 |
| Diabase | 78-1,050 |
| Basalt | 680 |
| Olivine-Diabase | 2,000 |
| Peridotite | 12,500 |

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[1] Adapted from C.A. Heiland, "Geophysical Exploration" (from Costello, 1980

Metal location and depth of burial can be inferred from the shape and width of the anomaly. The location of metal using magnetometry facilitates safe excavation without puncturing metal containers. Underground utilities, which are traceable with magnetics, often lie within loosely filled trenches that may provide permeable pathways for groundwater flow. Magnetrometry is used in clearing drilling sites to select locations that are free of drums, detectable under ground utilities, and other ferrous obstructions.

Under certain conditions where sufficient contrasts in magnetic susceptibilities between geologic units exist, magnetic methods may be useful in identifying geologic structures such as folding, faulting, buried drainage channels, bedrock topography, and igneous intrusions. The magnetic susceptibilities of some rock materials are presented in Exhibit 8.4-10.

### 8.4.2.4.2 Procedures

Preliminary Considerations

Before conducting a magnetometer survey at a hazardous waste site, the following tasks should be conducted:

- Review historical waste disposal practices to identify target and nontarget buried ferrous objects.
- Establish the minimum size target of interest.

- Conduct onsite reconnaissance to evaluate the suitability of the method, possible interferences, and terrain features.

- Review site geology to determine if any natural anomalies might exist.

- Estimate anticipated anomaly intensities.

For clearing drilling sites, utility maps should always be consulted.

Onsite reconnaissance is conducted to identify possible interferences and to evaluate accessibility of the areas to be surveyed. Interferences may result from surface metal, fences, buildings, and powerlines.

Metal near the sensor may produce an anomaly great enough to mask an anomaly produced by a buried object below it, depending on the relative anomaly strengths.

The presence of variable geologic conditions, such as mafic intrusions and local magnetite sand accumulations, may give rise to natural interferences. Geologic features that produce anomalies often lie below the depth of burial of the target objects and thus may not affect detection of the targets significantly.

The following tasks are involved in the magnetometer survey:

- Establishing a survey grid over the study area

- Establishing a base station

- Collecting magnetometer measurements at each station

### 8.4.2.4.3 Survey Design

Magnetic measurements are usually taken either at equally spaced stations located across a rectangular grid or at equal intervals along several profile lines. The spacing of the stations depends on the target size. In general, the spacing between stations should be approximately one-fourth of the lateral extent of the target. For a single 55-gallon drum, the maximum distance at which the station can be detected is typically 10 to 15 feet, and the grid spacing can be designed accordingly. The closer the stations are spaced, the better the resolution becomes and the better the probability of detecting anomalies. More stations are required to cover the same area, however, and the time required to conduct the survey increases correspondingly.

It is helpful to lay out the survey grid so that the lines are oriented perpendicular to the strike of the target. If this orientation is not known, then north-south grid lines are preferable.

An accuracy of 5 percent is generally adequate for station locations for a magnetometer survey; hence, a hand transit (Brunton compass) and tape measure are sufficient to survey the station locations. Wooden stakes or other nonmetallic station markers should be used.

#### Magnetic Measurements

Magnetic measurements are taken by placing the magnetometer at a station, orienting the sensor properly, and taking the reading in accordance with the operating instructions for the particular instrument used. The instrument operator should be free of any magnetic material such as keys, belt buckles, steel-toed shoes, metal rim glasses, and so forth. To avoid effects of rocks that may be naturally magnetic and to avoid the effects of topography, it is important to hold the magnetometer sensor above the ground while taking measurements. The sensor should be held at the same height above the ground for each measurement.

### Interferences

Interferences from surface metals, fences, powerlines, and other aboveground sources, which generally lie closer to the magnetometer sensor than buried targets, may mask the targets and sometimes cannot be corrected for. In some cases, data obtained near such interferences must be excluded. Corrections for interferences from geologic conditions and surface objects that have small magnetic moments in comparison to the target may be possible. Some instruments have filters that eliminate powerline interferences.

### Total Field Versus Vertical Gradient

Two types of magnetic measurements are generally used: total field and vertical gradient. The total magnetic field intensity is a scalar measurement, or simply the magnitude of the earth's field vector independent of its direction. The magnetic field gradient is a measurement of the difference in the total magnetic field between two sensors having a fixed distance between them. The gradient equals the change in total magnetic field over distance (sensor spacing). For vertical gradient measurements, the sensors are separated vertically. Gradient measurements may be made by using a gradiometer, which is a magnetometer with two sensors built in, or by using a normal total field magnetometer and taking two separate readings at different heights. The gradiometer takes measurements at the two sensors simultaneously, whereas measurements using a total field magnetometer have a small time separation. The sensitivity of vertical gradient measurements is variable and depends in part on the vertical separation of the two sensor positions. Commonly, vertical separations of one-half, 1, and 2 meters are used.

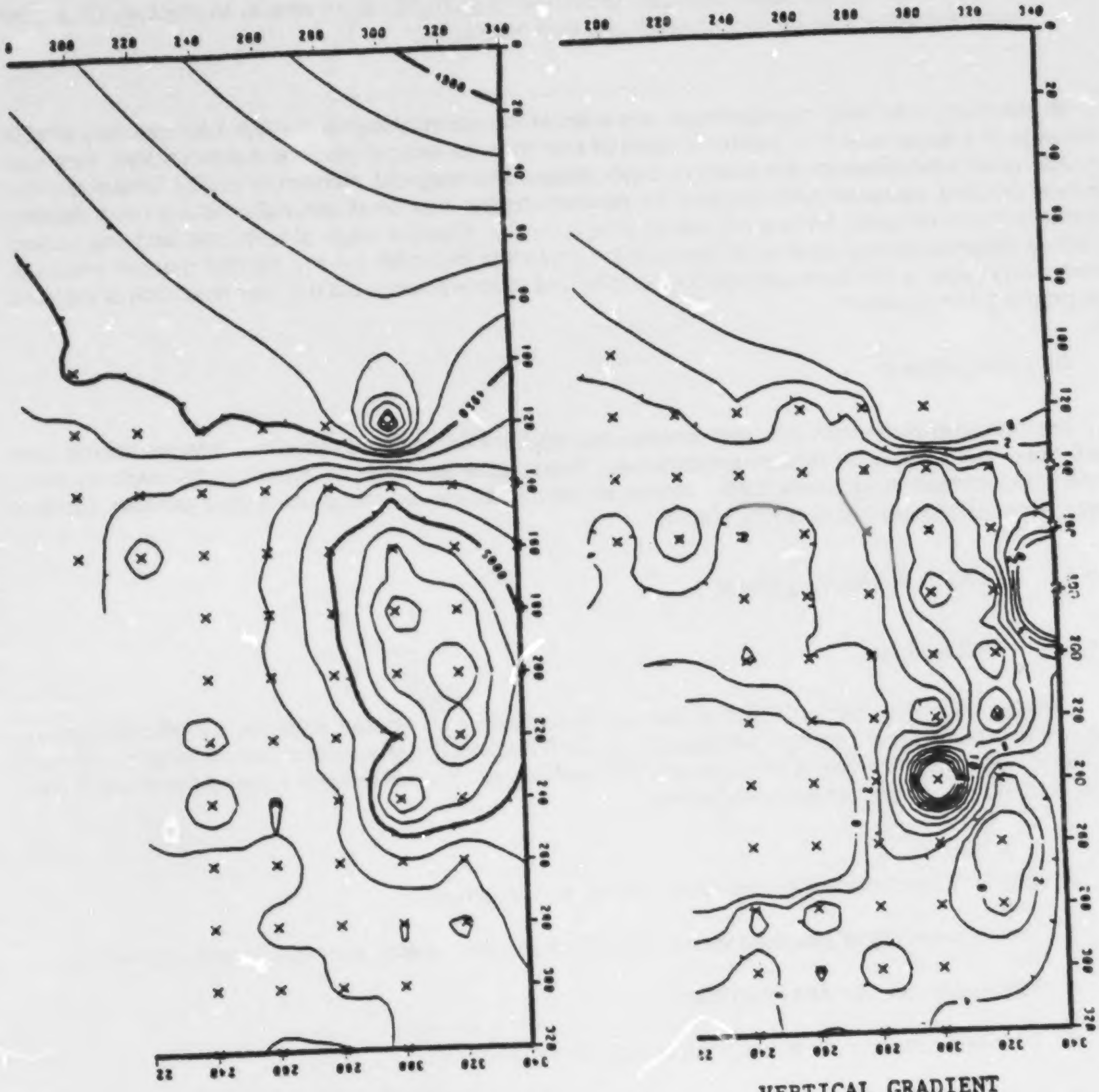
Vertical gradient measurements include several advantages over total field measurements:

- The measurements give finer resolution of complex anomalies.
- The measurements require no corrections for diurnal variation, micropulsations, and magnetic storms. Measurements at the two sensors are made simultaneously or nearly so; these temporal variations affect both readings essentially equally and are, therefore, removed on the differential.
- The regional magnetic field affects measurements at both sensors equally, and these variations are removed on the differential.
- Gradient measurements provide vector direction as well as magnitude and can be used for more quantitative determination of anomaly location, depth, shape, and magnetic moment.

The following are disadvantages of the gradiometer and reasons why total field measurements may be preferred:

- Gradiometers have a smaller radius of detection and thus require closer spacing of measurement points to achieve their potential for finer resolution of anomalies. Finer grid spacing requires more time. In some cases, targets at depth may be beyond the radius of detection for a gradiometer, but not for a total field magnetometer.

## Exhibit 8.4-11
## CONTOUR MAPS OF TOTAL FIELD AND VERTICAL GRADIENT MEASUREMENTS


200
220
240
260
280
300
320
340
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320

TOTAL MAGNETIC FIELD

Contours are in gammas +50,000

VERTICAL GRADIENT

Contours are in gamma/0.5 meter

- Gradient readings using a total field magnetometer take longer to do than a simpler field measurement.
- Calculations that are based on vector properties of gradient measurements to precisely determine source location may be very complex and time consuming.

In summary, total field measurements are suitable for reconnaissance surveys because they enable coverage of a larger area in a shorter amount of time than do vertical gradient measurements; they also provide good information on the location, depth, shape, and magnetic moment of buried ferrous objects. Vertical gradient measurements are best for detailed studies over small anomalies where more detailed characterization of buried ferrous objects may be required. Contour maps of both total field and vertical gradient measurements over a small anomaly are presented in Exhibit 8.4-11. Vertical gradient measurements were taken at the same grid spacing as total field measurements, but the finer resolution of the vertical gradient data is evident.

#### Data Interpretation

Interpretation of the data can yield location and depth of the magnetic sources. Interpretation is best performed using computer modeling techniques. Reasonable estimates of depth can be made by using methods described in Appendix 8.4D. Almost all interpretations are made using data profiles. Contour maps establish the distribution of the source.

### 8.4.2.5 Ground Penetrating Radar

#### 8.4.2.5.1 Applicability

Ground penetrating radar (GPR) data are used to produce a continuous subsurface profile through the use of a linear strip chart recorder. However, while GPR is useful to define subsurface conditions, it is more limited in application than most other geophysical techniques. The following is a partial list of major uses related to hazardous waste site investigations:

- Define or locate buried drums, tanks, cables, and pipelines.
- Define boundary of disturbed versus original ground (and strata), such as a landfill or a trench.
- Map water table (limited reliability).
- Delineate stratigraphic layers, such as clay, till, or sands.
- Define natural subsurface features, such as buried stream channels (preferential pathways), lenses, and voids (caves).

In addition, GPR may be used whenever a significant change (or differential) in electrical properties is encountered and when a change should be mapped. For more specific information on these properties, the reader should refer to the theory or information sources subsections in this compendium.

Although GPR cannot provide definitive information on subsurface conditions, the data are desirable for several reasons. GPR can quickly provide subsurface information about a hazardous waste site. Typical productivity with conventional graphic recording GPR equipment on low-relief terrain is several line miles per day. Often, this productivity rate makes GPR a very cost-effective reconnaissance method. For example, if the objective of an investigation is to define suspected locations of buried drums, then GPR (or other geophysical methods, electromagnetics, or magnetics) can be used to define suspected areas. Test pit excavation (or other direct methods) can be used to further explore suspected areas and can provide control for GPR data.

### 8.4.2.5.2 Procedures

#### Preliminary Considerations

#### A. Objectives

GPR capabilities should be evaluated against the objectives of hazardous waste site investigations. If the site study is simply to substantiate the possibility of buried drums on a site with minimal effort, then typical radar surveys will provide only localized detail and no direct evidence. If, however, a site is to be characterized in detail and the identification of any drum location is a priority, GPR alone or in conjunction with other geophysical methods (such as magnetometry) may be a cost-effective way of directing test pit operations and selecting sampling points, etc.

#### B. Existing Data

If radar equipment is identified as theoretically capable of providing the type of information desired, further evaluation should be made to determine if the equipment is appropriate to use with the conditions found at a particular site. Evaluation of existing data can identify problems that may be encountered in the field, such as the presence of buried electrical cables or a near-surface conductive clay layer. Conditions such as these can cause noise in the data or even "mask" (block out) the radar signal from a deeper target. An analysis of the site history might aid in further defining a survey area and might result in a cost savings. Deep targets may be out of the practical range of many typical GPR units. For example, most radar antennae that are in general use would probably yield poor results if they were used to define the top of a bedrock surface underlying 300 feet of highly conductive overburden.

### 8.4.2.5.3 Survey Design

#### A. Define Survey

Once the GPR survey objectives have been clearly defined, the existing information has been reviewed, and reconnaissance of the site has been conducted, attention should be given to the design of the geophysical survey. The detail (coverage, resolution) required of a radar survey is a primary factor in designing and planning fieldwork. If the survey is to provide reconnaissance information on the possibility of buried drums onsite, then a grid using a wide (50- to 200-foot) line spacing may be appropriate. If the purpose is to define as many drum locations as possible (such as for removal), then a detailed survey is probably required (10- to 20-foot line spacing). The importance of designing and implementing a grid system tied into existing "permanent" features (such as roads and buildings) cannot be overstated. This design will allow the grid to be reproduced (if required) for enforcement purposes and will also help to locate anomalous areas for future fieldwork (such as sampling, drilling, or digging test pits) by use of the grid for points of reference. Under certain circumstances, a reproducible grid may not be needed, such as if the raw field data are going to be used to direct other field operations, but this situation is not typical.

The anticipated size of the target compared with the proposed survey area should have an impact on the detail of the GPR survey grid. To reliably locate a suspected target would require more effort (such as denser line spacing or use of a higher resolution transmitter antennae) for a smaller target than would be required for a larger one. In this compendium, a discussion of reliably locating a target refers to the probability of the GPR unit passing over the surface expression of a target. Reliably locating a target does not mean that the target will be clearly defined in the data. Site-specific factors such as poor field methods, target depth, and background noise may cause a target to be overlooked or misinterpreted.

### B. Background Noise

Background noise can be a significant factor in the success of a GPR survey. Evaluation of existing data and a site reconnaissance will help to determine the probable background noise level. A high noise level can make interpretation of data difficult. Noise often varies across a large (several hundred acres) site as different site conditions (soils, overburden stratigraphy, etc.) are encountered. If the natural soils have a wide variation in electrical properties, it would be difficult to pick out a subsurface boundary between backfill material and natural undisturbed soils. Noise sources can be divided into two groups: natural, such as surface water, discontinuous clay layers, extremes in topographic relief, and steeply dipping strata; and cultural, such as powerlines, surface metal, and two-way radios. Experience is important, because there is little published information on instrument sensitivity to different noise sources. Generally, however, the more conductive a target is above (or below) the normal background noise, the easier targets are to define and interpret.

### C. Limitations

GPR instruments are limited with regard to sensitivity, resolution, and penetration. Field experience, published references, and operator's manuals should be used when an evaluation of instrumentation versus capability is desired.

Interpretation of radar data generally becomes more complex as the contrast in electrical properties (between background areas and target areas) becomes less. Several small closely spaced targets may not be sensed as multiple anomalies but as one large anomaly. This inaccuracy is a result of the inherent resolution capabilities of the equipment. Penetration of the signal varies with transmitter frequency, electrical conductivity, changes in conductivity, noise, and so forth. Because there are many limitations with GPR equipment and methods, the SM should consult a geophysicist before conducting the actual radar survey (as outlined in the responsibilities subsection).

## 8.4.2.5.4 Miscellaneous Considerations

### A. Calibration

Geophysical instruments require calibration; GPR is no exception. Because the often subtle changes in the profile record chart can be interpreted in various ways, GPR equipment should be subject to an intensive calibration process.

Because the internal timing mechanism is used to estimate depths, it should be checked periodically with an internal or external timer. Because electrical properties (inherent to travel times) are quite variable between sites, the radar unit should be calibrated to each condition (strata) found at the site. This calibration can be as simple a process as taking some readings on top of a conductor at a known depth, such as a buried pipeline, and seeing how this reading translates to the strip chart profile. GPR subcontractors commonly make statements such as "on the strip chart, 1 inch equals so many feet." Statements like these should be viewed skeptically because if materials vary across a site, then so do their corresponding electrical properties, which are directly responsible for travel time and depth calculations. Records of the calibrations and procedures that are used should be entered in the appropriate equipment and/or project file.

Interpretation

The interpretation of GPR data requires professional training and experience and is beyond the scope of this compendium. However, buried metal targets, such as steel drums, may be easily recognized by the novice. Exhibit 8.4-12 has been included to give an example of radar data and to show how evident buried metal targets can be. The ground surface is at the top of the page; depth increases toward the bottom of the page. On the far left side (OE) of the profile, a strong signal is received at the bottom of the profile (at depth). In the middle of the line (75E to 100E), however, the reflected signal is weak and badly distorted. In this location, penetration does not extend to the bottom of the figure.

## 8.4.3 BOREHOLE GEOPHYSICS

Borehole geophysical techniques provide subsurface information on rock and unconsolidated sediment properties and fluid movement. Although the oil and mineral industries have been using these borehole geophysics for many years, only recently have the techniques been adopted to the assessment of site hydrogeologic conditions. This subsection provides an introduction to the basic borehole geophysical techniques as they might be applied to a hazardous waste site investigation. References are included to complement and expand on the technical interpretation of the logging results.

### 8.4.3.1 Applicability

Discussion in this subsection will introduce a variety of borehole geophysical methods. The general logging categories discussed are electrical, nuclear, sonic, and mechanical. Although other borehole techniques are available, such as three-dimensional vertical seismic profiling, borehole televiewing, and a variety of crossbore techniques, these are not discussed in detail in this compendium. A combination of surface and borehole techniques offers a three-dimensional understanding of subsurface conditions, but that approach is also beyond the introductory detail in this compendium.

A very basic description of the log, the parameters that affect response, and the sensing devices are presented here to aid in evaluating the applicability of logging functions.

A number of techniques are not discussed in this compendium; information on these techniques may be obtained from the references at the end of this subsection. While examining the techniques that are included in the following discussion, the reader should refer to Exhibit 8.4-13, which was taken in part from the D'Apollonia report to the U.S. Army (1980). The exhibit presents each logging function and information obtained for a variety of geologic and hydrologic parameters.

#### 8.4.3.1.1 Electrical

Electrical logging includes spontaneous potential and single point resistance.

**Spontaneous Potential (SP):** The response is the result of small differences in voltage caused by chemical and physical contacts between the borehole fluid and the surrounding formation. These voltage differences appear at lithology changes or bed boundaries, and their response is used quantitatively to determine bed thickness or formation water resistivity. Qualitative interpretation of the data can help identify permeable beds.

In a consolidated rock aquifer system where groundwater flow is controlled by secondary permeability (i.e., fractures), SP response may be generated from a streaming potential caused by a zone gaining or losing water.

The SP log is a graphic plot of potentials between the downhole sonde and a surface electrode. The system consists of a moveable lead electrode (located in the sonde) that traverses the borehole and a surface electrode (mud plug) that measures potentials in millivolts. Noise and anomalous potentials are relatively common in SP logs and are discussed in electric log anomalies later in this compendium.

**Single-Point Resistance:** This technique is based on the principle of Ohm's Law ($E = Ir$) where $E$ is voltage measured in volts, $I$ is current measured in amperes, and $r$ is resistance measured in ohms. Single-point resistance measures the resistance of in situ materials (of the rock and the fluid) between an in-hole electrode and a surface electrode. Resistance logging has a small radius of investigation and is very sensitive to the conductivity of the borehole fluid and changes in hole diameter (caving, washouts, and fractures). This condition is advantageous for the operator in that any change in the formation (resistance or fractures) will produce a corresponding change in resistance on the log. These changes in resistance are interpreted to be a result of lithology changes. The single-point log is very desirable for geologic correlation because of its special response to lithology changes.

In crystalline rock (high resistance formations), single-point resistance logs are useful in locating fractures and often appear as mirror images (opposite deflections) to the caliper log. Hole enlargement, caving, washouts, and fractures appear as excursions to the left (indicating less resistance in normal operation) of the more typical response observed in this log.

The principle of the function is quite simple. The current ($I$) remains constant while the voltage ($E$) is measured between the movable lead electrode and the surface electrode. Voltage is then converted internally to resistance using Ohm's Law. A diagram of this arrangement can be found in Exhibit 8.4-14. SP and single-point resistance logs are designed to be run simultaneously since single-point resistance operates in alternating current (AC) (110 volt) while the SP operates in direct current (DC).

### 8.4.3.1.2 Nuclear

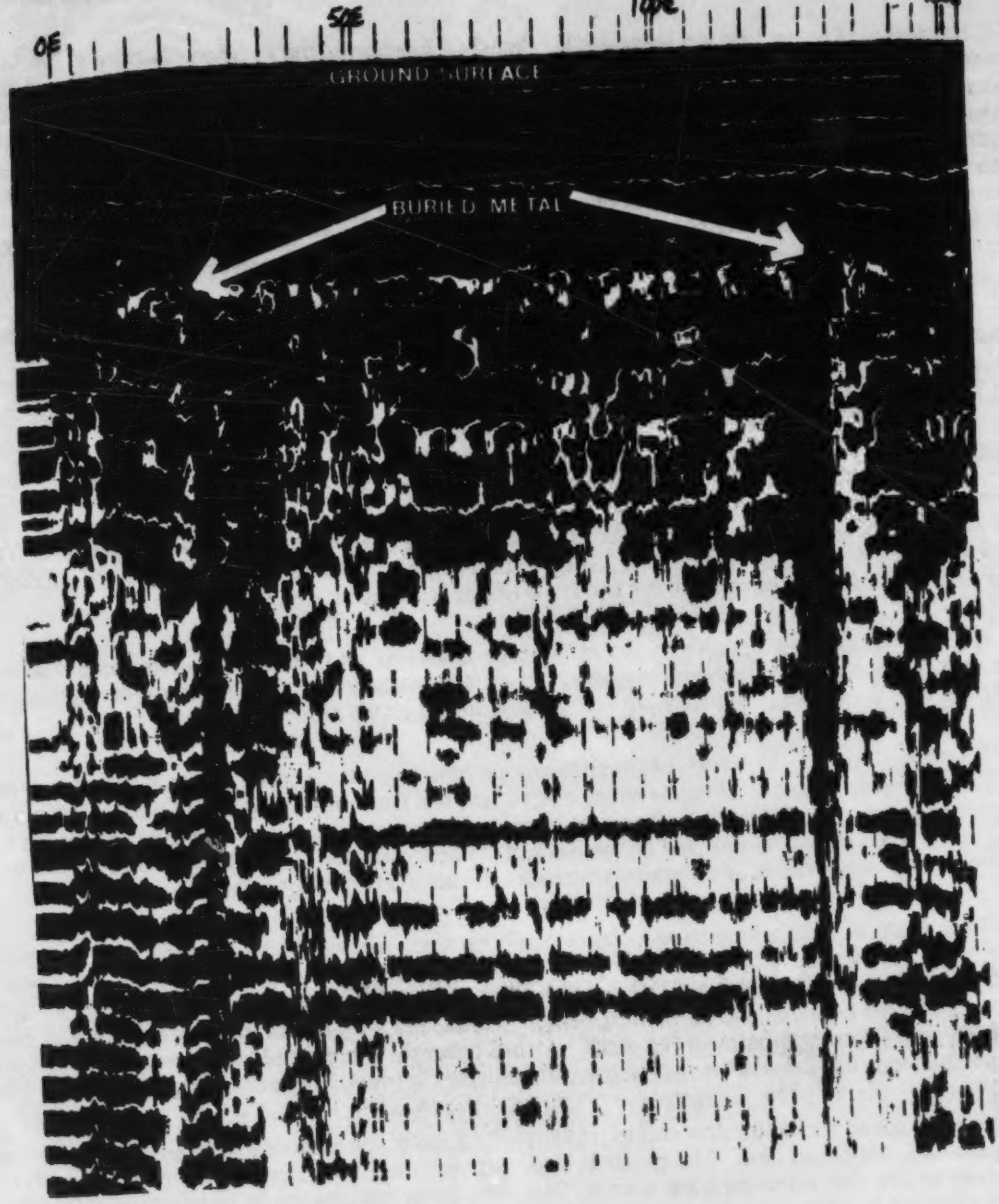
Nuclear logging includes natural gamma, gamma-gamma, and neutron.

**Natural Gamma:** This log measures the total of naturally occurring gamma radiation that is emitted from the decay of radioisotopes normally found in rocks. Typical elements that emit natural gamma radiation and cause an increase on the log are potassium 40 and daughter products of the uranium and thorium decay series. The primary use of natural gamma logging is lithology identification in detrital sediments where the fine-grained (most often clay) units have the highest gamma intensity. A natural gamma log can be quite useful to the hydrologist, hydrogeologist, or geohydrologist, because clay tends to reduce permeability and effective porosity within a sedimentary unit. This log can also be used to estimate (within one geohydrologic system) which zones are likely to yield the most water.

The sensing device is a scintillation-type receiver that converts the radioactive energy into electrical current, which is transmitted to the instrument and generates the natural gamma log.

Natural gamma logs can be run in open or cased boreholes filled with water or air. The sensing device is often built into the same sonde that conducts SP and single-point resistance logs. In essence, three functions are available from the use of one sonde.

## Exhibit 8.4-12
## TYPICAL GPR PROFILE



**Gamma-Gamma:** This nuclear log uses an activated source and measures the effect of the induced radiation and its degradation. Gamma-gamma logs are widely used to determine bulk density from which lithologic identification is based. They may also be used to calculate porosity when the fluid and grain density are known. The radius of investigation is dependent on two factors: source strength and source-detector spacing. Typically, 90 percent of the response is from within 6 to 10 inches of the borehole.

**Neutron:** The neutron log response is primarily a function of the hydrogen content in the borehole environment and surrounding formation. This content is measured by introducing neutrons into the borehole and surrounding environment and by measuring the loss of energy caused by elastic collision. Because neutrons have no electrical charge and have approximately the same mass as hydrogen, hydrogen atoms are, therefore, responsible for the majority of energy loss. Neutron logging is typically used to determine moisture content above the water table and total porosity below the water table. Information derived from this log is used to determine lithology and stratigraphic correlation of aquifers and associated rocks. Inferred data can be used to determine effective porosity and specific yield of unconfined aquifers. Neutron logging is also very effective for locating perched water tables.

The equipment is identical to that described for the gamma-gamma log except for use of a different source and the fact that the equipment must be able to handle higher count rates.

#### 8.4.3.1.3 Mechanical

Mechanical logging includes caliper, temperature, fluid conductivity, and fluid movement.

**Caliper:** This log is defined as a continuous record of the average diameter of a drill hole. Caliper sondes can have from one to four arms. The two basic types are bowstring units, which are connected at two hinges, and finger devices, which have single hinges (see Exhibit 8.4-15).

Caliper resolution is broken into two categories: horizontal and vertical. The horizontal resolution is the ability of the tool to measure the true size of the hole regardless of its shape (circular or elliptical). Vertical resolution is controlled by the length of the feeler contact on the borehole wall.

Traditionally, caliper logs have been run to correct other logging functions. If this is the primary reason for running caliper, the bowstring or single-hinged unit will both provide adequate data. Calipers using single-hinged feelers provide the best vertical resolution. Interchangeable arms are available for the single-hinged tools and should be selected on the basis of the hole diameter. Single-hinged tools can be used to identify fractures in igneous and metamorphic rocks and solution openings in limestone.

**Temperature:** The temperature log provides continuous records of the borehole fluid environment. Response is caused by temperature change of the fluid surrounding the sonde, which generally relates to the formation water temperature. The borehole fluid temperature gradient is highly influenced by fluid movement in the borehole and adjacent rocks. In general, the temperature gradient is greater in low-permeability rocks than high-permeability rocks, which is probably the result of groundwater flow. Therefore, temperature logs can provide the hydrologist with valuable information regarding groundwater movement.

Logging speed should be slow enough to allow adequate sonde response with depth, because there is a certain amount of lag time. The probe is designed to be run from top to bottom (downward) in the borehole to channel water past the sensor. Because some disturbance is inevitable when the sonde moves through the water column, repeat temperature logs should be avoided until the borehole fluid has had time to reach thermal equilibrium.

Exhibit 8.4-13

## EVALUATION OF GEOPHYSICAL METHODS APPLIED TO GEOLOGICAL AND HYDROLOGICAL CONDITIONS

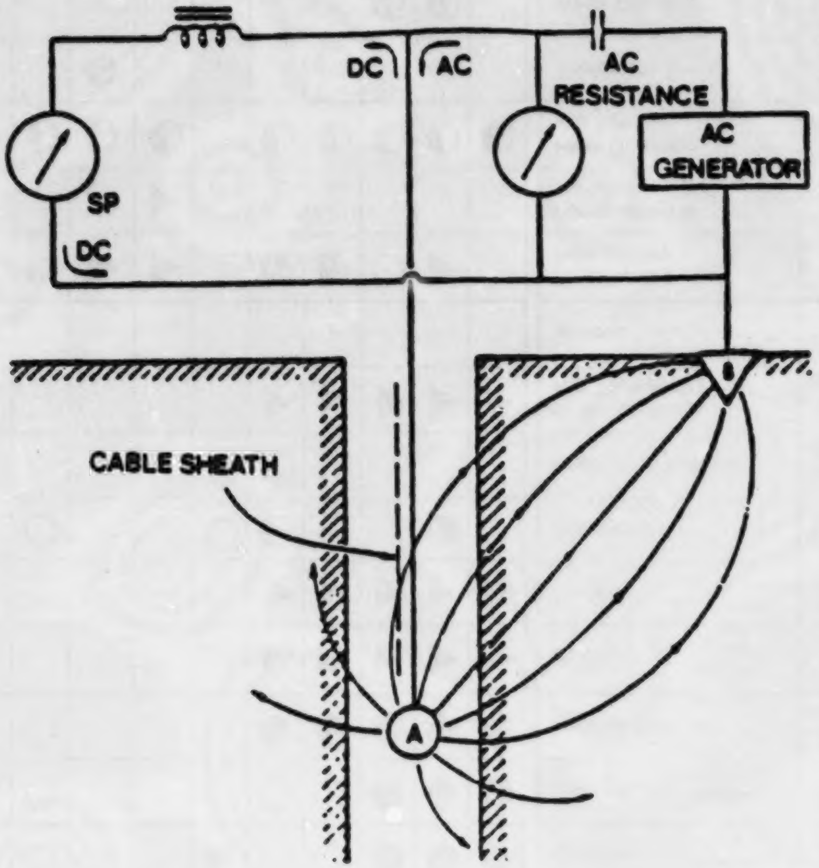
GEOPHYSICAL METHOD EVALUATION

| Geophysical Method Evaluation | |
|---|---|
| ● | Best Information |
| ○ | Good Information |
| ◐ | Partial Information |
| ▲ | Inferred Information |
| □ | No Information |

| GEOPHYSICAL METHODS | BOREHOLE LOGGING | STRATIGRAPHY | | | GEOLOGIC STRUCTURE | | | | | | AQUIFER PROPERTIES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lithology | Lithologic Correlation | Surficial Materials | Folding | Faulting | Fracturing | Dissolution Features | Buried Drainage and Topography | Igneous Features | Porosity and Permeability | Potentiometric Surface | Flow Direction and Rate | Temperature | Water Chemistry |
| | Spontaneous Potential | ● | ● | ● | ▲ | ▲ | | | ▲ | | | | ◐ | | |
| | Resistance | ● | ● | ● | ▲ | ▲ | ● | | ▲ | | ▲ | | ◐ | | ◐ |
| | Natural Gamma Radiation | ● | ● | ● | ▲ | ▲ | | | ▲ | | ○ | | ◐ | | ◐ |
| | Gamma-Gamma | ○ | ○ | ● | ▲ | ▲ | ○ | ○ | ▲ | | ● | | ◐ | | |
| | Neutron | ○ | ○ | ● | ▲ | ▲ | ○ | ○ | ▲ | | ● | | ◐ | | |
| | Caliper | ▲ | | | | | ○ | ○ | | | | | | | |
| | Fluid Movement | | | | | | | | | | ▲ | ▲ | ◐ | | |
| | Temperature | | | | | | | | | | ▲ | ▲ | ◐ | ● | |
| | Sonic | ○ | ○ | ○ | | | ○ | | | | ● | | ◐ | | |
| | Fluid Conductivity | | | | | | | | | | | | | | ○ |

SOURCE: D'Appolonia Report to U.S. Army Toxic and Hazardous Materials Agency 1980.

## Exhibit 8.4-14
## CONVENTIONAL SIMULTANEOUS SINGLE-ELECTRODE RESISTANCE AND SPONTANEOUS-POTENTIAL LOGGING SYSTEM


DC
AC
AC
RESISTANCE
AC
GENERATOR
SP
DC
B
CABLE SHEATH
A

SOURCE: Guyod (1952).

**Fluid Conductivity:** These logs provide a continuous measurement of the conductivity of the borehole fluid between two electrodes. The contrast in conductivity can be associated with water quality and possibly with recharge zones. Conductivity logs are helpful when interpreting electric logs, because both are affected by fluid conductivity.

The most common sonde measures the AC voltage drop across closely spaced electrodes. These electrodes actually measure the fluid resistivity (which is the reciprocal of conductivity), but they are called fluid conductivity logs to avoid confusion with resistivity logs. Simply, conductivity logs actually measure the resistance of the borehole fluid; resistance logs measure the resistance of the rocks and the fluid they contain.

**Fluid Movement:** Fluid movement logging can be broken into two components: horizontal and vertical. Horizontal logging uses either chemical or radioactive tracers, is most often unacceptable for hazardous waste investigations, and will not be discussed in detail.

Vertical movement of fluid in the borehole is measured by either an impeller flowmeter or chemical tracers. Tracers will not be discussed in this subsection for the reason mentioned above. The impeller flowmeter response is affected by the change in vertical velocity within the borehole. The best application of this log is defining fluid movement in a multiaquifer artesian system.

The sonde consists of a rotor or vanes housed inside a protective cage or basket. This log should be run both downhole and uphole. The logs should be compared side by side; only those anomalies that have mirror (opposite) deflections are the zones that are providing the vertical movement (Exhibit 8.4-16).

**Sonic:** This logging (also called acoustic logging) uses sound waves to measure porosity and to identify fractures in consolidated rock. Two general types of measurements are internal transit time, which is the reciprocal of velocity, and amplitude, which is the reciprocal of attenuation. The amplitudes of the $P$- and $S$-waves are directly related to the degree of consolidation and porosity and to the extent and orientation of fractures.

The instrumentation of acoustic logging is very complex; it includes a downhole sonde with a transmitter and two to four receivers. Sound waves are emitted from the transmitter and their propagation is measured by the receivers.

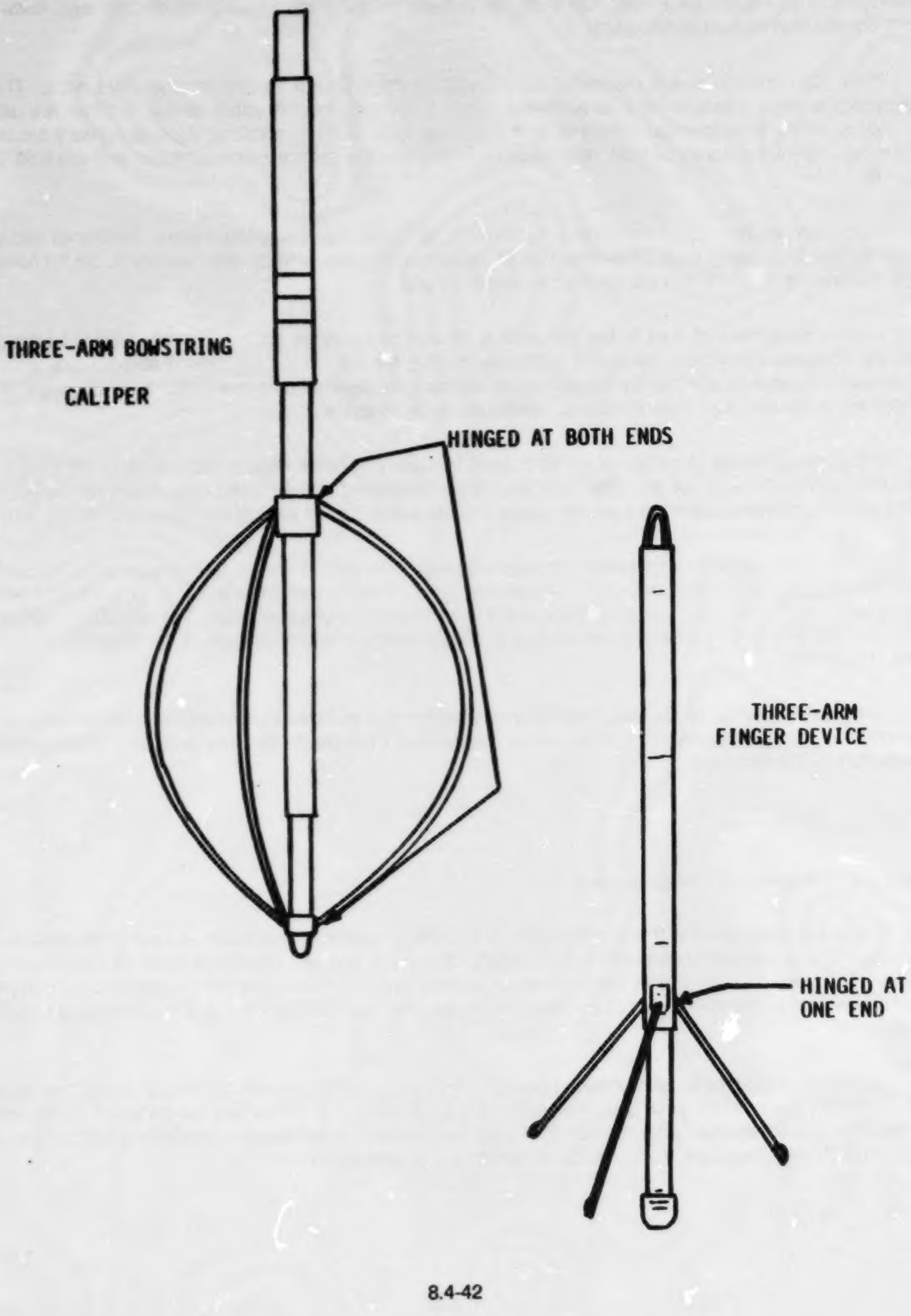
## 8.4.3.2 Procedures

### 8.4.3.2.1 Preliminary Considerations

Equipment discussed in this compendium is capable of performing electric, nuclear, and mechanical logging. This equipment is available from a variety of vendors and can usually be rented for short periods of time or leased on a long-term basis. In any case, the application of these techniques is quite complex, and the project geophysicist should be contacted to provide input for planning and implementing borehole programs.

The study objectives must be defined clearly before the user can identify the proper equipment needs. For instance, the Site Manager (SM) must generally understand the subsurface environment to determine which logs are applicable. After evaluating this determination and the site-specific limiting factors (i.e., access to well, well diameters, etc.), the SM can select the proper equipment.

**Exhibit 8.4-15**
**TWO TYPES OF CALIPER SONDES**


THREE-ARM BOWSTRING
CALIPER
HINGED AT BOTH ENDS
THREE-ARM
FINGER DEVICE
HINGED AT
ONE END

The following general types of information could be expected from borehole measurements:

- Vertical changes in porosity
- Relative vertical changes in permeability and transmissivity
- Lithology and structure
- Lithologic conditions
- Vertical distribution of leachate plumes
- Groundwater gradients, flow direction, and rate
- Water quality parameters

To determine a logging program that will enhance evaluation of the site, the SM must thoroughly evaluate two key items. First, the SM must identify the regional bedrock geology (i.e., igneous, sedimentary, metamorphic) and typical surficial units. Then the SM must gather as much local information as possible regarding geologic units (i.e., boring logs of monitoring wells, domestic water supply depths, and well yields) and any hydrogeologic reports or information.

Second, the SM must identify which logs are applicable in the site's geologic setting and which logs will provide the required information for meeting program objectives. Exhibit 8.4-17 is a general guide to data collection objectives that will aid in the selection process. However, each function under consideration must be researched in more detail using publications listed in information sources in this compendium and consulting with borehole geophysical logging specialists.

There are, of course, limiting factors for each of the logging techniques. Exhibit 8.4-18 identifies some limiting factors for the logs.

Once the geologic environment has been evaluated and the logging functions narrowed, the SM must select the appropriate equipment. Portable units that can be carried on a backpack enable access to most well locations; however, they are limited to logging functions requiring low power operation (e.g., battery packs).

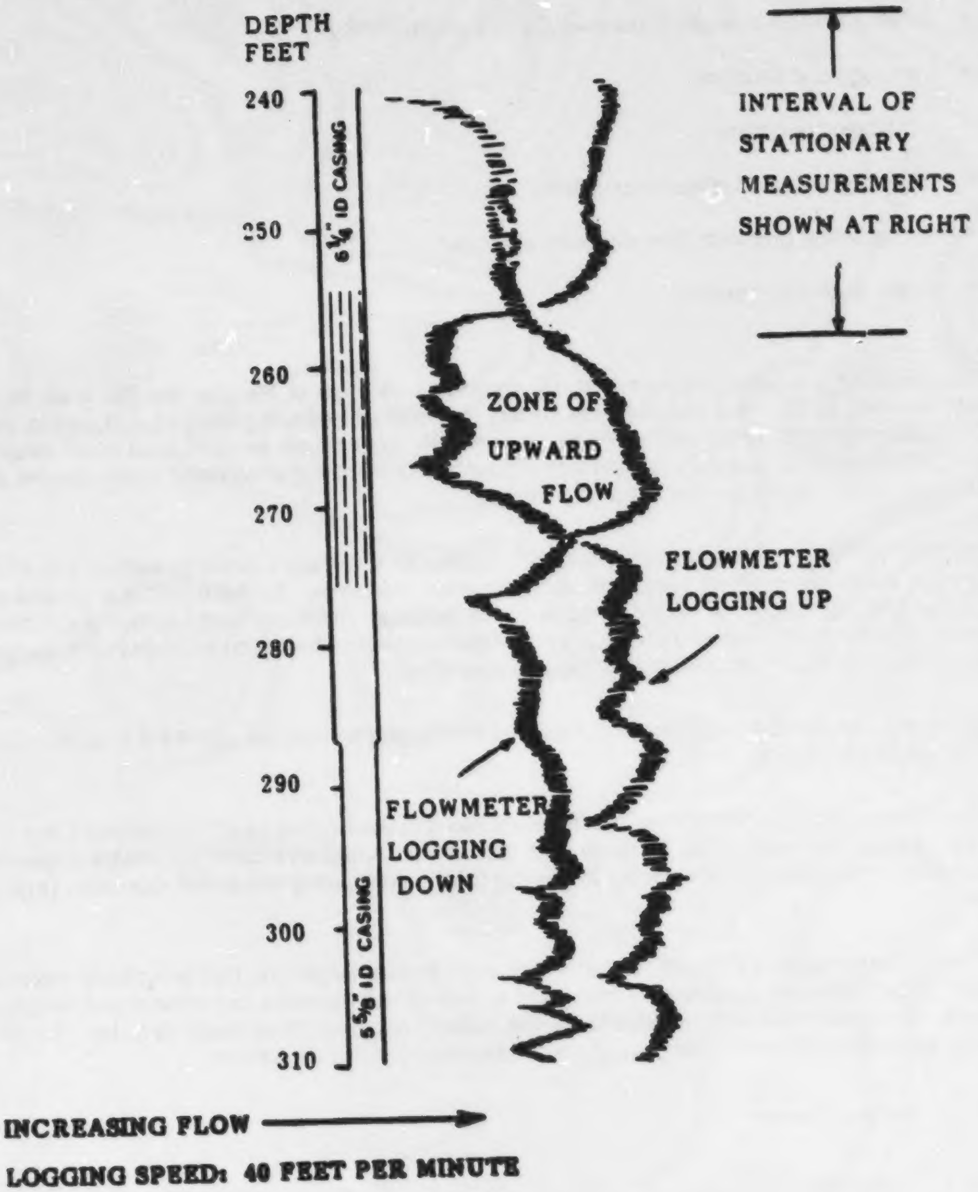
Functions that require 110 volt AC usually operate from a larger unit that is typically mounted in a vehicle. These units cost considerably more, and access to well locations can present problems in swampy areas. However, these units are able to run the majority of log functions available today. Exhibit 8.4-19 shows a generalized schematic diagram of geophysical well-logging equipment.

### 8.4.3.3 Survey Design

#### 8.4.3.3.1 Log Selection

Once the SM has defined the logging program and has identified the general category of logs that will supply the necessary information, the specific logging functions(s) can be selected. Exhibit 8.4-20 describes the type of log, a basic description, and the primary use of the technique.

## Exhibit 8.4-16
## CONTINUOUS FLOWMETER LOG USED TO LOCATE ZONES OF FLOW



SOURCE: Techniques of Water Resources Investigations of the United States Geological Survey, Chapter E1 page 110.

## Exhibit 8.4-17
## GENERAL GUIDE TO DATA COLLECTION OBJECTIVES

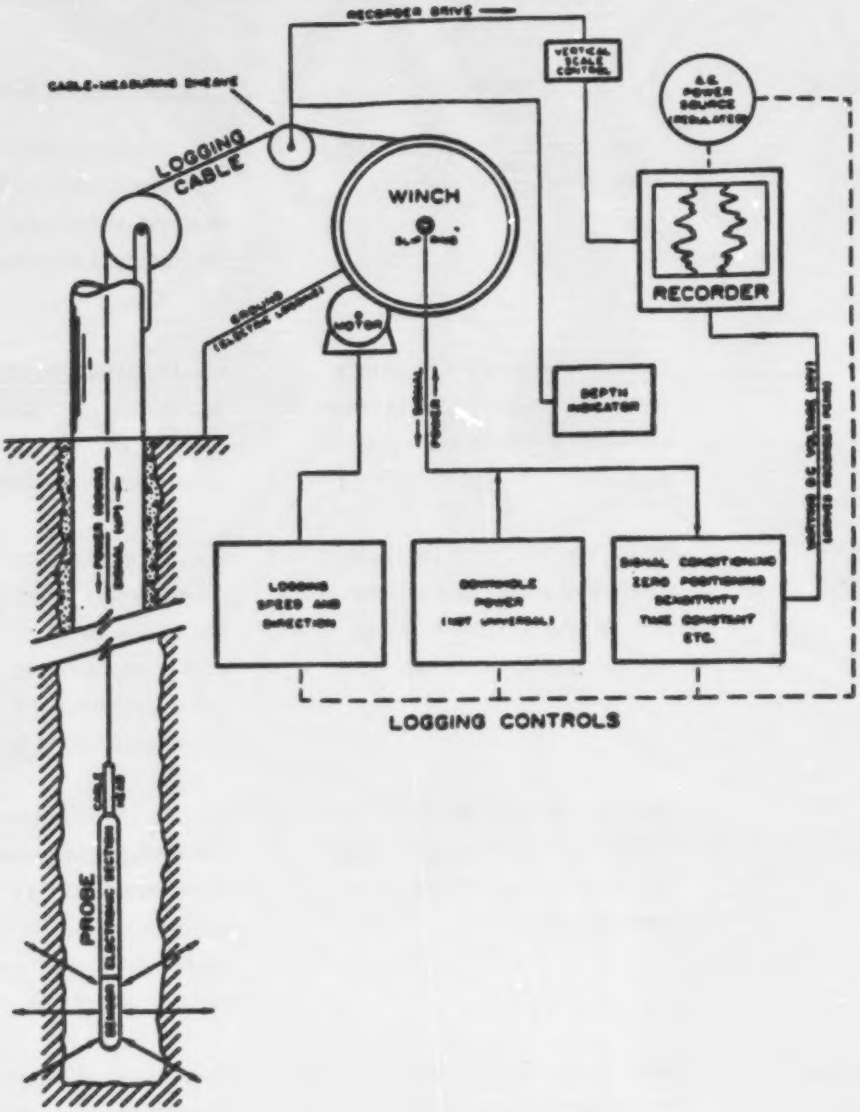
| Data Collection Objectives | Available Techniques |
|---|---|
| Lithology and stratigraphic correlation | Electric, caliper, nuclear, and sonic |
| Total porosity or bulk density | Gamma-gamma, neutron, and sonic |
| Effective porosity or true resistivity | Long-normal resistivity (records the resistivity beyond the invaded zone) |
| Clay or shale content | Natural gamma |
| Secondary permeability (fractures, solution openings) | Caliper, electric, sonic, and borehole televiewer |
| Specific yields of unconfined aquifer | Neutron |
| Water level and saturated zones | Electric, neutron, gamma-gamma temperature, and fluid conductivity |
| Moisture content | Neutron |
| Dispersion, dilution, and movement of waste | Fluid conductivity and temperature |
| Groundwater movement through a borehole | Flowmeter (vertical) and chemical tracers (horizontal) |
| Cementing | Caliper, temperature, gamma-gamma, and sonic |
| Casing corrosion | Caliper |

## Exhibit 8.4-18
## LOGGING FUNCTIONS BOREHOLE LIMITATIONS

| | Limiting Factors | | |
|---|---|---|---|
| Logging Function | Uncased Open Boreholes | Minimum Diameter (inches) | Fluid Filled |
| Spontaneous potential | X | 2.5 | X |
| Single-point resistance | X | 2.5 | X |
| Natural gamma | | 2.5 | |
| Gamma-gamma | | 2.5 | |
| Neutron | | 2.5 | |
| Caliper | | 2.0 | |
| Temperature | X | 2.0 | X |
| Fluid conductivity | X | 2.5 | X |
| Fluid movement | X | 2.5 | X |
| Sonic | X | 2.5 | X |

X = Required condition

## Exhibit 8.4-19
## SCHEMATIC BLOCK DIAGRAM OF GEOPHYSICAL WELL-LOGGING EQUIPMENT


RECORDER DRIVE
VERTICAL SCALE CONTROL
CABLE-MEASURING SHEAVE
A.C. POWER SOURCE (REGULATED)
LOGGING CABLE
WINCH
SLIP RING
RECORDER
GROUND (ELECTRIC LOGGING)
MOTOR
SIGNAL
POWER
DEPTH INDICATOR
POWER DOWN
SIGNAL UP
LOGGING SPEED AND DIRECTION
DOWNHOLE POWER (NOT UNIVERSAL)
SIGNAL CONDITIONING
ZERO POSITIONING
SENSITIVITY
TIME CONSTANT
ETC.
LOGGING CONTROLS
CABLE HEAD
PROBE
ELECTRONIC SECTION
SENSOR

**SOURCE:** Techniques of Water Resources Investigations of the United States Geological Survey, Chapter E1 page 22.

## Exhibit 8.4-20
## TYPES OF LOGS, DESCRIPTIONS, AND USES

| Type of Log | Description | Primary Utilization |
|---|---|---|
| Caliper | A caliper produces a record of the average diameter of drill hole. | Used for correction of other logs, identification of lithology changes, and locations of fractures and other openings in bedrock |
| Single-Point Resistivity | This log measures the resistance of the earth material lying between an in-hole electrode and a surface electrode. | Used to determine stratigraphic boundaries, changes in lithology, and the identification of fractures in resistive rock |
| Spontaneous Potential (SP) | SP is a graphic plot of the small differences in voltage that develop between the borehole fluid and the surrounding formation. | Used for geologic correlation, determination of bed thickness, and separation of nonporous from porous rocks in shale-sandstone and shale-carbonate sequences |
| Natural Gamma | This log measures natural gamma radiation emitted from potassium 40, uranium, and thorium decay series elements. | Used for lithology identification and stratigraphy correlation; most advantageous in detrital sediment environments where the fine-grained units have the highest gamma intensity |
| Gamma-Gamma | Gamma photons are induced in the borehole environments, and the absorption and scattering are measured to evaluate the medium through which they travel. | Used for identification of lithology, measurements of bulk density, and porosity of rocks |

## Exhibit 8.4-20
## (continued)

| Type of Log | Description | Primary Utilization |
|---|---|---|
| Neutron | Neutrons are introduced into the borehole, and the loss of energy is measured from elastic collision with hydrogen atoms. | Used to measure the moisture content above the water table and the total porosity below the water table |
| Temperature | A temperature log is the continuous record of the thermal gradient of the borehole fluid. | Used to determine seasonal recharge to a groundwater system |
| Fluid Conductivity | This log provides a measurement of the conductivity of the in-hole fluid between the electrodes. | Used primarily in conjunction with electric logs to aid in their interpretation; useful for identifying saltwater intrusion into freshwater systems; can be useful in evaluating water quality |
| Acoustic (sonic) | A transmitter and a receiver or series of receivers that use various acoustic frequencies. These signals are introduced into the borehole, and the elastic waves are measured. | Used to measure porosity and identify fractures in igneous and metamorphic rock. |

There are many combinations of logging functions. The reader should refer to Exhibit 8.4-12 (D'Apollonia, 1980) for more information on logging functions. Generally, several borehole techniques are performed simultaneously or in a series to define any one of the geologic or hydrologic parameters.

### 8.4.3.4 Interferences / Anomalies

**Electrical:** Both SP and resistance logs are susceptible to the same types of interference. Buried cables, pipelines, magnetic storms, and the flow of groundwater can all cause anomalous readings. The most common noise in the SP logs is known as the battery effect and is caused by the polarization of the wetted cable. This condition is most troublesome in highly resistive surface formations. A common interference with the resistance log is the result of ground currents from powerlines and other electrical sources that interfere with the alternating current used in logging. This interference appears as a sine wave superimposed on the resistance curve.

Some common equipment problems with electric logs are presented in Exhibit 8.4-21.

**Nuclear:** The most common problems with nuclear logs are that they are all affected by borehole diameter changes and changes in borehole media (air, water, mud). These problems are why caliper logs are essential to correlate the results. A natural gamma log is the sum of the radiation emitted from the formation and does not distinguish between elements (i.e., potassium, uranium, thorium). In quantitative applications of nuclear logs, the calibration, standardization, and correction for dead time are essential. However, when the logs are used for qualitative interpretations (e.g., stratigraphic correlation), such corrections may be unnecessary.

**Mechanical:** Caliper logging is a straightforward mechanical technique and exhibits few anomalies. Instrumental malfunctions are more likely to cause anomalous readings than borehole parameters.

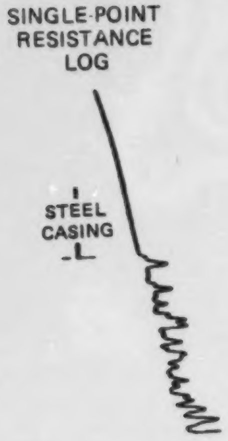
Impeller flow anomalies are most often caused by varying the probe position radially in the borehole. Bouncing of the probe from side to side will erroneously indicate flow. Corrective action may include a device that would hold the sonde in the middle of the borehole.

Temperature logs are susceptible to thermal lag time, self-heating, drift from the electronics in the sonde, and borehole conditions. A slow logging speed and additional logging functions (i.e., caliper, fluid conductivity) can aid in temperature log interpretation. Another problem with temperature logs is that after one pass of the sonde, the thermal gradient is disturbed and repeat logs may not be representative. In large diameter wells, convection can cause a disturbance of the thermal gradient.

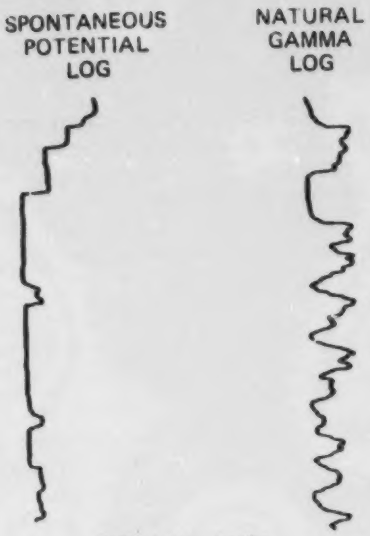
Disturbances to the borehole fluid caused by changes in fluid density and thermal convection can cause an erroneous log. Since fluid conductivity response is affected by the water chemistry, chemical equilibrium must be reached before measurements are taken. Well water may take months to obtain chemical equilibrium with the surrounding formation after drilling, and water wells with much internal movement may never reach chemical equilibrium. Repeat logs are not usually representative because the sonde disturbs the water column.

Cycle skipping is the most obvious unwanted signal in acoustic logging. It is caused by excessive signal attenuation in the fluid or by equipment malfunction. A problem with interpreting acoustic logs is that the velocity is dependent on a variety of lithologic factors, and the widely used time-average equation does not account for most of the factors.

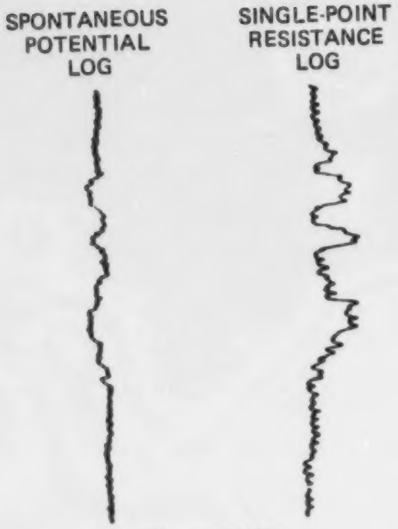
## Exhibit 8.4-21
## GEOPHYSICAL LOGS SHOWING SOME COMMON EQUIPMENT PROBLEMS



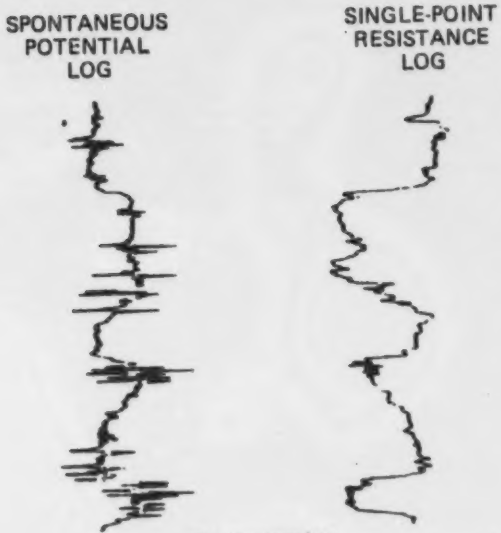
Drift Eliminator
not operating
properly



Different logs on the
same recorder amplifier
Pen drive sticking or
amplifier gain too low



Simultaneous logs
Regular noise due to
60-cycle AC



Simultaneous logs
Intermittent noise probably
caused by drilling equipment
of the well

**SOURCE:** Techniques of Water Resources Investigations
of the United States Geological Survey, Chapter E1, page 23.

# APPENDIX 8.4A

# ELECTROMAGNETIC (EM) INSTRUMENT

## THEORY

The conductivity value resulting from an electromagnetic (EM) instrument is a composite; it represents the combined effects of the thickness of soil or rock layers, their depths, and the specific conductivities of the materials. The instrument reading represents a combination of these effects, extending from the surface to the depth range of the instrument. The resulting values are influenced more strongly by shallow materials than by deeper layers, and this influence must be taken into consideration when interpreting the data. Conductivity conditions from the surface to the instrument's nominal depth range contribute generally 75 percent of the instrument's response. However, contributions from highly conductive materials lying at greater depths may have a significant effect on the reading.

EM instruments are calibrated to read subsurface conductivity in millimhos per meter (mm/m). These units are related to resistivity units in the following manner:

1,000/(millimhos/meter) = 1 ohmmeter
1,000/(millimhos/meter) = 3.28 ohmfeet

The advantage of using millimhos/meter is that the common range of resistivities from 1 to 1,000 ohmmeters is covered by the range of conductivities from 1,000 to 1 millimhos/meter.

Most soil and rock minerals, when dry, have very low conductivities (Exhibit 8.4A-1). On rare occasions, conductive minerals like magnetite, graphite, and pyrite occur in sufficient concentrations to greatly increase natural subsurface conductivity. Most often, conductivity is overwhelmingly influenced by water content and by the following soil / rock parameters:

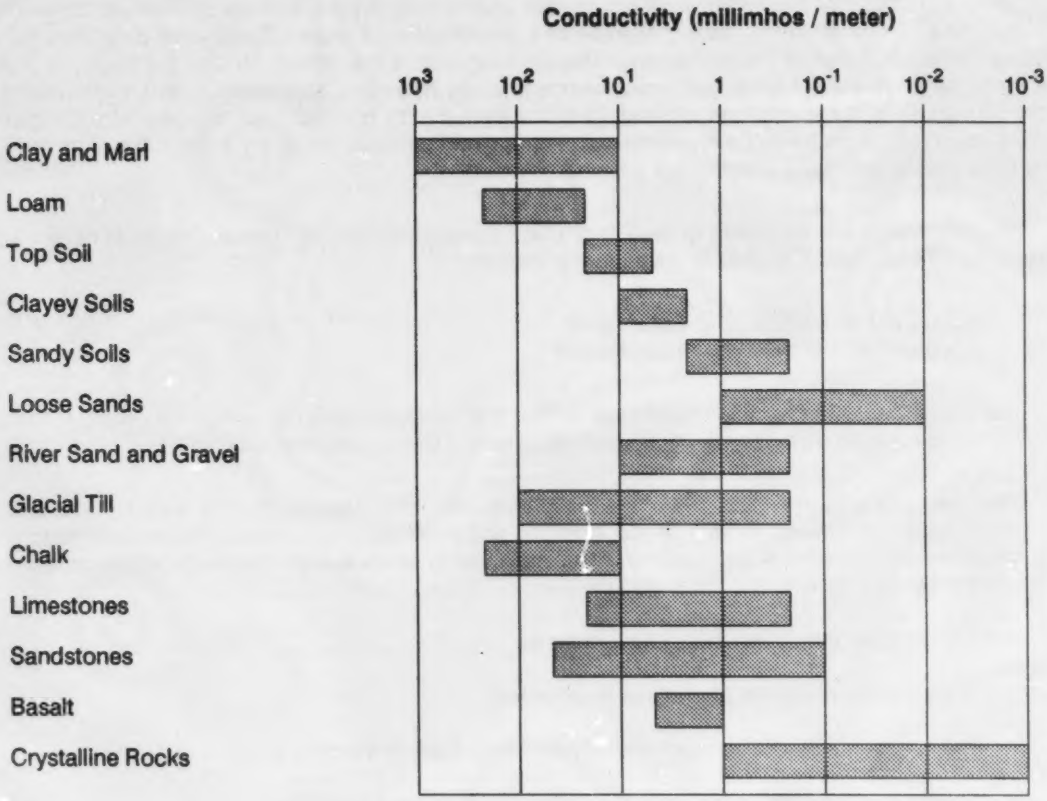
- The porosity and permeability of the material
- The extent to which the pore space is saturated
- The concentration of dissolved electrolytes and colloids in the pore fluids
- The temperature and phase state (i.e., liquid or ice) of the pore water

A specific conductivity value cannot be assigned to a particular material, because the interrelationships of soil or rock composition, structure, and pore fluids are highly variable.

In areas surrounding hazardous waste sites, contaminants may escape into the soil and the groundwater system. In many cases, these fluids contribute large amounts of electrolytes and colloids to both the unsaturated and saturated zones. In either case, the ground conductivity may be greatly affected, sometimes increasing by one to three orders of magnitude above background values. However, if the natural variations in subsurface conductivity are very low, contaminant plumes of only 10 to 20 percent above background may be mapped.

In the case of spills involving heavy nonpolar, organic fluids such as diesel oil, the normal soil moisture may be displaced, or a sizeable pool of oil may develop at the water table. In these cases, subsurface conductivities may decrease, causing a negative EM anomaly.

## Exhibit 8.4A-1
## CONDUCTIVITY (MILLIMHOS / METER)



SOURCE: Benson (1983). (Range of electrical conductivities in natural soil and rock, modified after Culley et al.)

## INFORMATION SOURCES

The following list of sources has been categorized into specific groups for easy use. A partial list of equipment manufacturers follows the references:

## Electromagnetic (EM) Theory and Interpretation

### Textbooks

Grant, F.S., and G.F. West. *Interpretation Theory in Applied Geophysics*. McGraw Hill Book Company. 1965.

Griffiths, D.H., and R.F. King. *Applied Geophysics for Geologists and Engineers*. Pergamon Press. 1981.

Parasins, D.S. *Principles of Applied Geophysics* (3rd edition). Chapman and Hall Publishers. 1979.

Telford, W.M., L.P. Geldard, R.E. Sheriff, and D.A. Keys. *Applied Geophysics*. Cambridge University Press.

Wait, J.R. *Geo-Electromagnetism*. Academic Press. 1982.

### Journals

Hanneson, J.E., and G.F. West. "The Horizontal Loop Electromagnetic Response of a This Plate in a Conductive Earth: Part I and II." *Geophysics*, Vol. 49, no. 4, pp. 411-432.

McNeill, J.D. "Electrical Conductivity of Soils and Rock." Technical Note #5. Mississauga, Canada: Geonics Limited. 1980.

McNeill, J.D. "Electromagnetic Terrain Conductivity Measurement at Low Industion Numbers." Technical Note #6. Mississauga, Canada: Geonics Limited. 1980.

McNeill, J.D. "Interpretative Aids for Use with Electromagnetic (Non Contacting) Ground Resistivity Mapping." Paper presented at European Association of Exploration Geophysicists Annual Meeting. Hamburg, Germany. 1979.

Wait, J.R. "A Note on the Electromagnetic Response of a Stratified Earth." *Geophysics*, Vol. 21, pp. 382-385.

### EM General Manuals

Benson, R.C., R.A. Glaccum, and M.F. Noel. "Geophysical Techniques for Sensing Buried Wastes and Waste Migration." Las Vegas, Nevada: U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory. 1983.

## EM Case Histories and Examples

### Journals

Fox, R.L., and D.A. Gould. "Delineation of Subsurface Contamination Using Multiple Surface Geophysical Methods." Presented at the NWWA Eastern Regional Groundwater Conference (Technology Division). Newton, Massachusetts. 1984.

Glaccum, R.A., R.C. Benson, and M.R. Noel. "Improving Accuracy and Cost-Effectiveness of Hazardous Waste Site Investigations. *Ground Water Monitoring Review.* Summer 1982.

McNeill, J.D. "Electromagnetic Resistivity Mapping of Contaminant Plumes." Presented at the National Conference on Management of Uncontrolled Hazardous Waste Sites—contact HMCRI. Silver Spring, Maryland.

Rudy, R.J., and J.A. Caolle. "Utilization of Shallow Geophysical Sensing at Two Abandoned Municipal/Industrial Waste Landfills on the Missouri River Floodplain." *Ground Water Monitoring Review.* Fall issue, 1984.

Slaine, D.D., and J.P. Greenhouse. "Case Studies of Geophysical Contaminant Mapping at Several Waste Disposal Sites." Presented at the NWWA Second National Symposium on Aquifer Restoration and Ground Water Monitoring. Columbus, Ohio. 1982.

Steward, M.T. "Evaluation of Electromagnetic Methods for Rapid Mapping of Salt-Water Interfaces in Coastal Aquifers." *Ground Water*, Vol. 20. September-October 1982.

### Manufacturers

Aerodat Limited
3883 Nashua Drive
Mississauga, Ontario L4V 1R3
416/671-2446 (airborne EM systems)

Crone Geophysics Limited
3607 Wolfedale Road
Mississauga, Ontario L5C 1V8
416/270-0096 (surface EM systems)

Geonics Limited
1745 Meyerside Drive
Mississauga, Ontario L5T 1C5
416/676-9580 (borehole and surface EM systems)

Phoenix Geophysics Limited
200 Yorkland Boulevard
Willowdale, Ontario M2J 1R5
416/493-6350 (surface EM systems)

Scintrex
222 Snidercroft Road
Concord, Ontario L4K 1B5
416/669-2280 (surface EM systems)

# APPENDIX 8.4B

# RESISTIVITY

## THEORY

The ability to conduct (or resist) current is dependent on the nature of the material to which the current is applied. Geologic materials, such as clays or iron-rich saturated sands, are generally quite conductive but are poor resistors, while organic-rich soils and granite bedrock are typically poor conductors and good resistors. The electrical resistivities in naturally occurring materials run a range of magnitudes whose extreme values differ by almost a factor of 10 to the 20th power (Grant and West). Exhibit 8.4B-1 gives some examples of how water content and geologic material can affect resistivity.

Although ER instrumentation is variable in design and operation, the basic principles are constant. Electrical resistivity has as its foundation Ohm's Law, which states that the electrical potential between two points is defined by the supplied current multiplied by the circuit resistance. Mathematically, Ohm's Law could be represented as follows:

$$E = IR$$

In the above equation,

$E$ = potential of the circuit (volts)
$I$ = current (amperes)
$R$ = the measured resistance (ohms), the desired parameter.

In practice, current ($I$) is introduced to the ground by conduction through (generally) two current electrodes. Generally, two potential electrodes ($E$) are put a set distance from the current electrodes, and the potential drop in current is measured. From this relationship, resistivity is calculated (Exhibit 8.4B-2). To supply the electrical current, a power source such as batteries or a generator can be used, but for most work done at hazardous waste sites, a DC battery supply will suffice.

## INFORMATION SOURCES

The following list of sources has been categorized into specific groups for easy use and includes a partial list of equipment manufacturers.

### Electrical Resistivity (ER) Theory and Interpretation

### Textbooks

Griffith, D.H., and R.F. King. *Applied Geophysics for Geologists and Engineers*. Pergamon Press. 1981.

Grant, F.S., and F.G. West. *Interpretation Theory in Applied Geophysics*. McGraw-Hill. 1965.

Telford, W.M., et al. *Applied Geophysics*. Cambridge University Press. 1976.

Exhibit 8.4B-1

# NATURAL VARIATIONS IN RESISTIVITY BECAUSE OF MATERIAL AND WATER CONTENT

| Rock Type | Water Content (percent $H_2O$) | Typical Resistivity (ohmmeter) |
|---|---|---|
| Siltstone | 0.54 | $1.5 \times 10^4$ |
| Siltstone | 0.38 | $5.6 \times 10^8$ |
| Coarse Grain Sandstone | 0.39 | $9.6 \times 10^5$ |
| Coarse Grain Sandstone | 0.18 | $10^8$ |
| Graywacke Sandstone | 1.16 | $4.7 \times 10^3$ |
| Graywacke Sandstone | 0.45 | $5.8 \times 10^4$ |
| Dolomite | 2.0 | $5.3 \times 10^3$ |
| Dolomite | 0.96 | $8 \times 10^3$ |
| Peridotite | 0.1 | $3 \times 10^3$ |
| Peridotite | 0 | $1.8 \times 10^7$ |
| Granite | 0.31 | $4.4 \times 10^3$ |
| Granite | 0 | $10^{10}$ |
| Basalt | 0.95 | $4 \times 10^4$ |
| Basalt | 0 | $1.3 \times 10^8$ |
| Olivine-Pyrox. | 0.028 | $2 \times 10^4$ |
| Olivine-Pyrox. | 0 | $5.6 \times 10^7$ |
| Material | | |
| Clays | | 1-100 |
| Sands | | 10 - 800 |
| Sea Water | | 0.2 |
| Groundwater (bedrock) | | 0.5 - 100 |
| Groundwater (overburden) | | 100 |

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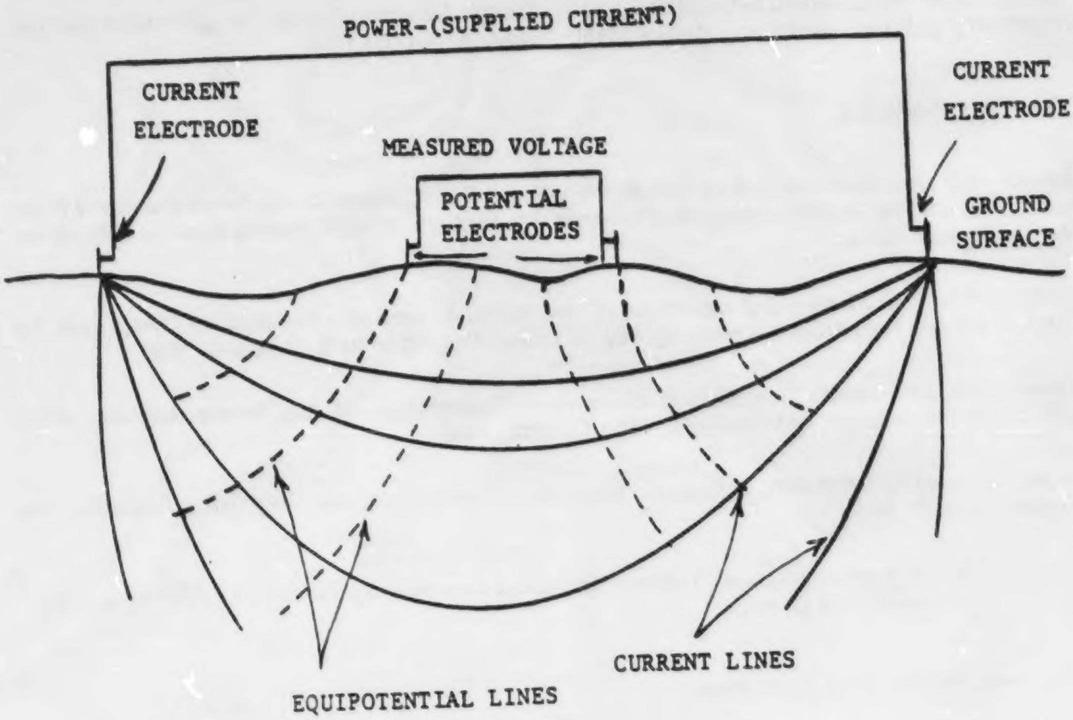
Based on W.M. Telford, et al. Applied Geophysics, 1976.

## Exhibit 8.4B-2
## THEORY OF ELECTRICAL RESISTIVITY MEASUREMENTS


POWER-(SUPPLIED CURRENT)
CURRENT ELECTRODE
MEASURED VOLTAGE
POTENTIAL ELECTRODES
CURRENT ELECTRODE
GROUND SURFACE
CURRENT LINES
EQUIPOTENTIAL LINES

## Journals

Zohdy, A.A.R. "Automatic Interpretation of Schlumberger Sounding Curves Using Modified Dar Zarrovk Functions." *U.S. Geological Survey Bulletin* 1313E. Washington, D.C. 1975.

## ER General Manuals

Benson, R.D., R.S. Glaccum, and M.R. Noel. *Geophysical Techniques for Sensing Buried Wastes and Waste Migration.* Prepared by Technos, Incorporated, for the U.S. Environmental Monitoring Systems Laboratory. Las Vegas, Nevada. 1983.

Costello, R.L. *Identification and Description of Geophysical Techniques.* Prepared by D'Appolonia for U.S. Army Toxic and Hazardous Materials Agency. Aberdeen Proving Ground, Maryland. 1980.

Greenhouse, J.P. *Surface Geophysics in Contaminant Hydrogeology.* Manual for the Hydrology Field School through the University of Waterloo, Ontario, Canada. 1982.

Peffer, J.R., and P.G. Robelen. *Affordable: Overburden Mapping Using New Geophysical Techniques.* Pit and Quarry. August 1983.

Technos, Incorporated. *Application Guidelines for Selected Contemporary Techniques for Subsurface Investigations.* (No publication date given.)

## ER Case Histories and Examples

## Journals

Bradbury, K.R., and R.W. Taylor. "Determination of the Hydrologic Properties of Lakebeds Using Offshore Geophysical Surveys." *Ground Water,* Vol. 22, No. 6. 1984.

Evans, R.B., and G.E. Schweitzer. "Assessing Hazardous Waste Problems." *Environmental Science Technology*, Vol. 18, No. 11. 1984.

Pennington, D. "Selection of Proper Resistivity Techniques and Equipment for Evaluation of Groundwater Contamination." Presented at the NWWA Conference on Surface and Borehole Geophysical Methods in Groundwater Investigation. Fort Worth, Texas. February 1985.

Ringstad, C.A., and D.C. Bugenig. "Electrical Resistivity Studies to Delimit Zones of Acceptable Ground Water Quality." *Ground Water Monitoring Review.* Fall 1984.

Underwood, J.W., K.J. Laudon, and T.S. Laudon. "Seismic and Resistivity Investigations near Norway, Michigan." *Ground Water Monitoring Review.* Fall 1984.

## Manufacturers

ABEM-Atlas Copco
Distributed by Geotronics Corp.
10317 McKalla Place
Austin, Texas 78758

Bison Instruments, Inc.
5708 West 36th Street
Minneapolis, Minnesota 55416

BRGM-Syscal
Distributed by EDA Instruments
5151 Ward Road
Wheat Ridge, Colorado 80033

Phoenix Geophysics Limited
200 Yorkland Boulevard
Willowdale, Ontario M2J 1R5

Scintrex Limited
222 Snidercroft Road
Concord (Toronto), Ontario L4K 1B5

# APPENDIX 8.4C

# SEISMICS

## THEORY

## SEISMIC REFRACTION

Compressional waves ($P$-waves), shear waves ($S$ waves), and surface waves are generated by a seismic disturbance such as a chemical explosion or weight drop; these waves propagate through the earth at seismic velocities determined by the physical properties of the subsurface material through which they travel (Exhibits 8.4C-1 and 8.4C-2). Particle motion associated with $P$-waves occurs in the direction of wave propagation as a series of compressions and refractions. The $P$-wave velocity diminishes markedly when the $P$-wave encounters water bearing strata. Layer density can be empirically deduced from the observed $P$-wave velocity by using the Nafe-Drake relation (Exhibit 8.4C 3).

Particle motion associated with $S$-waves occurs in a plane perpendicular to the direction of wave propagation. $S$ waves travel at slower seismic velocities than $P$-waves, $S$ waves always arrive at surface receivers after $P$-waves, and $S$-waves will not travel through fluids.

Surface waves are known as guided waves because they travel along a free surface of discontinuity within the earth. Particle motion and seismic velocity for these waves depend on the type of surface waves generated, but they all travel at lower velocities than either $P$- or $S$-waves. Whenever a $P$- or $S$-wave strikes an interface at an oblique angle, both reflected and refracted $P$- and $S$-waves are generated, serving to further complicate the identification of later arriving phases.

Shallow refraction surveys conducted in hazardous waste site investigations are run at high amplifier gain settings to record accurate arrival times of the first-arriving $P$-waves or the "first breaks." No effort is made to correlate arrival times of later-arriving phases.

$P$-waves travel along ray paths that are determined by Fermat's Principle, Huygen's Principle, and Snell's Law. $P$ waves arrive at receivers with seismic wave amplitudes that are determined by the geometrical rate of spreading of the wave and the attenuation of the spectral components of the wave form as a result of the imperfect elasticity of earth materials. The direct ray travels directly from source to receiver through the uppermost subsurface layer (layer 1 in Exhibit 8.4C-4) at $P$-wave velocity $V_0$. The total time taken by this ray to travel through layer 1 is given by :

$$t_{dir} = X/V_0$$

where $X$ is the shot-to-receiver distance.

This equation describes straight line segment 1 of the travel-time curve in Exhibit 8.4C-4, which has slope $1/V_0$ and passes through the origin.

When a $P$-wave encounters a boundary between two layers of different seismic velocities, part of the original wave energy is reflected back into the underlying layer at an angle of reflection $i_r$ that is equal to

## Exhibit 8.4C-1
## SEISMIC VELOCITIES OF COMPRESSIONAL AND SHEAR WAVES

| Material | Velocity (km/sec) | | Velocity (1000 ft/sec) | | Remarks |
|---|---|---|---|---|---|
| | α | β | α | β | |
| Alluvium | 0.5–2.0 | — | 1.64–6.56 | — | Near surface |
| | 3.0–3.5 | — | 9.84–11.48 | — | 2000 m depth |
| Clay | 1.1–2.5 | — | 3.61–8.20 | — | |
| Loam | 0.8–1.8 | — | 2.62–5.91 | — | |
| Loess | 0.3–0.6 | — | 0.98–1.96 | — | |
| Sand | | | | | |
| Loose | 0.2–2.0 | — | 0.66–6.56 | | |
| Loose | 1.0 | 0.4 | 3.28 | 1.31 | Above water table |
| Loose | 1.8 | 0.5 | 5.91 | 1.64 | Below water table |
| Calcareous | 0.8 | — | 2.62 | — | |
| Wet | 0.75–1.5 | — | 2.46–4.92 | — | |
| Weathered layer | 0.3–0.9 | — | 0.98–2.95 | — | |
| Glacial | | | | | |
| Till | 0.43–1.04 | — | 1.41–3.41 | — | Unsaturated |
| Till | 1.73 | | 5.67 | | Saturated |
| Sand and gravel | 0.38–0.50 | — | 1.25–1.64 | — | Unsaturated |
| Sand and gravel | 1.67 | | 5.48 | | Saturated |
| Sandstone-shale | | | | | |
| Tertiary | 2.1–3.5 | | 6.89–11.48 | | |
| Cretaceous | 2.4–3.9 | | 7.87–12.80 | | Depth range |
| Pennsylvanian | 2.9–4.4 | | 9.51–14.44 | | 0.3–3.6 km |
| Ordovician | 3.3–4.5 | | 10.83–14.76 | | 0.3–2.1 km |
| Sandstone | 1.4–4.3 | | 4.59–14.11 | | |
| Sandstone Conglomerate | 2.4 | | 7.87 | | Australia |
| Limestone | | | | | |
| Soft | 1.7–4.2 | | 5.58–13.78 | | |
| Hard | 2.8–6.4 | | 9.19–21.00 | | |
| Solenhofen | 5.97 | 2.88 | 19.59 | 9.45 | |
| U.S. midcontinent | — | 2.75 | | 9.02 | |
| and Gulf Coast | 3.4–6.1 | — | 11.15–20.01 | | |
| Argillaceous, Texas | 6.03 | 3.03 | 19.78 | 9.94 | ∥ to bedding |
| Argillaceous, Texas | 5.71 | 3.04 | 18.73 | 9.97 | ⊥ to bedding |
| Dolomitic, Penn. | 5.97 | — | 19.59 | | |
| Cement rock, Penn. | 7.07 | — | 23.20 | | |
| Crystalline, Texas, N.M., Okla. | 5.67–6.40 | — | 18.60–21.00 | — | |
| Dense, U.S.S.R. | 5.90–7.00 | 3.03–3.59 | 19.36–22.97 | 9.94–11.78 | |
| Salt, carnallite, sylvite | 4.4–6.5 | — | 14.44–21.38 | | |
| Caprock, salt, anhydrite, gypsum, limestone | 3.5–5.5 | — | 11.48–18.04 | | |
| Anhydrite, midcontinent and Gulf Coast | 4.1 | — | 13.45 | | |
| Gypsum | 2.0–3.5 | — | 6.56–11.48 | | |
| Chalk, U.S., | 2.1–4.2 | 1.07 SV | 6.89–13.78 | 3.51 SV | |
| Germany, France, | 2.58 | 1.13 SH | 8.46 | 3.71 SH | ⊥ bedding |
| Austin, Texas | 3.05 | — | 10.01 | | ∥ to bedding |
| Slate, Mass. | 4.27 | 2.86 | 14.01 | 9.38 | |
| Hornfels slate | 3.5–4.4 | — | 11.61–14.44 | — | |
| Magnetite ore | 5.50 | — | 18.04 | 10.81–10.49 | $V_P/V_S$ = 1.67–1.72 |
| Marble | 3.75–6.94 | 2.02–3.86 | 12.30–22.77 | 6.63–12.66 | 46 samples |
| | 5.78 | 3.22 | 18.96 | 10.56 | Average of 46 samples |
| Quartzite | 6.1 | — | 20.01 | — | |
| Wet clay, U.S.S.R. | 1.50–1.65 | — | 4.90–5.41 | 0.36–1.20 | $V_P/V_S$ ~ 4.5–13.7 |
| Impermeable argillaceous clay | 2.00 | 0.59 | 6.56 | 1.94 | |
| Soil | 0.11–0.20 | — | 0.36–0.66 | 0.59–1.27 | $V_P/V_S$ ~ 1.7–2.0 |
| Tuff | 2.16 | 0.83 | 7.09 | 2.72 | |

*Source.* These values have been selected from the compilation by Frank Press in the *Handbook of Physical Constants*, rev. ed., Memoir 97, and are printed with permission of the Geological Society of America. Copyright © 1966.

## Exhibit 8.4C-2
## SEISMIC VELOCITIES OF COMPRESSIONAL IN NEW ENGLAND

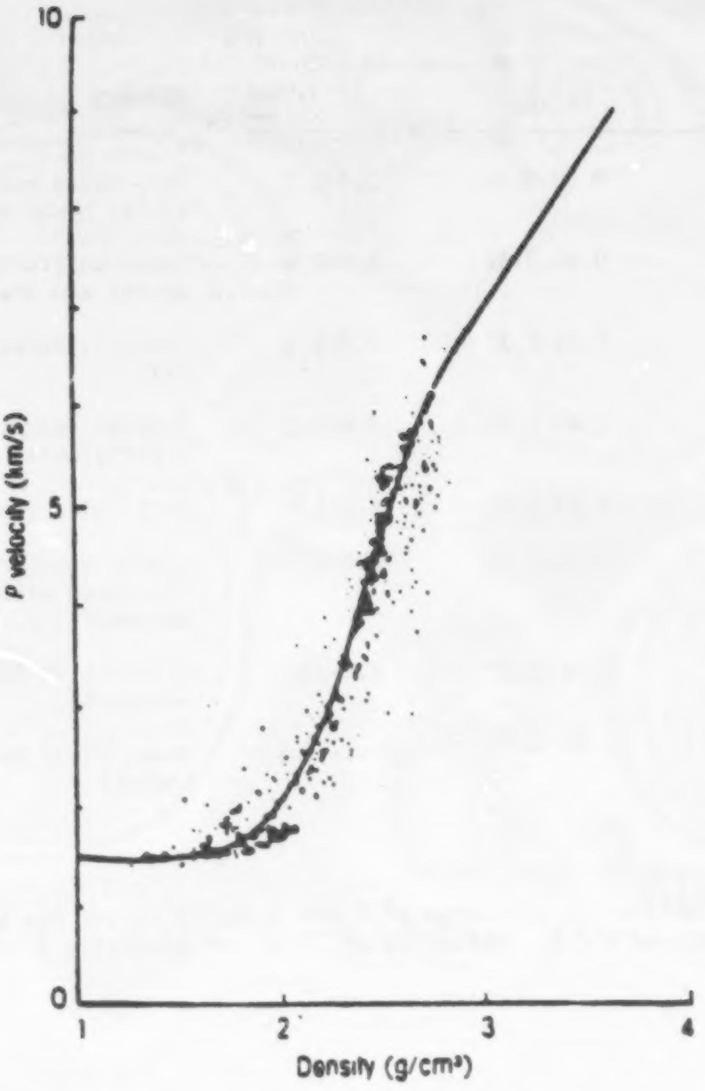
| MATERIALS | P-wave velocity<br>KM/sec | <br>$10^3$ ft/sec | REMARKS |
|---|---|---|---|
| Overburden | 0.09-0.30 | 0.3-1.0 | Very loose unsaturated silts, humus and fill. |
| | 0.30-0.61 | 1.0-2.0 | Loose unsaturated coarse gravel and ground moraine |
| | 0.92-1.37 | 3.0-4.5 | Compact, dense glacial till. |
| | 1.46-1.62 | 4.8-5.3 | Compact saturated flurioglacial deposits. |
| | 1.83-2.44 | 6.0-8.0 | Very dense glacial till. |
| Bedrock | 1.52-2.44 | 5.0-8.0* | Highly weathered, highly fractured with high permeability. |
| | 2.44-3.66 | 8.0-12.0 | Slightly to moderately weathered. |
| | 3.66-3.96 | 12 .0-13.0 | Unweathered massive bedrock. |

* Bedrock velocities in the range of 5,000 to 8,000 ft/sec may be highly fractured and be indicative of layers of extensive groundwater flow.

SOURCE: These values were compiled by the Weston Geophysical Corporation and listed in the Seismic Refraction Study of the Tinkhams site in Londonderry N.H.

Best available copy

## Exhibit 8.4C-3
## NAFE-DRAKE CURVE



RCE: R. E. Sheriff (1984).

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the angle of incidence *i*. The remainder of this energy is refracted into the underlying layer at an angle of refraction $i_r$.

When a *P*-wave strikes an interface between two layers at an angle $i = i_c$ so that $\sin i_c = V_1/V_2$ and $i_r = 90$, a pulse of small amplitude is generated in the overlying layer. This pulse is called the "head wave" and travels along the upper boundary of the underlying layer. The angle $i_c$ is the critical angle of refraction, and seismic rays striking the interface as angles of incidence greater than $i_c$ are totally reflected back into the overlying layer. The greater the velocity contract between the two layers, the greater the proportion of incident wave energy returned to the surface in the form of the reflected ray and the smaller the amplitude of the head wave.

Time-distance or travel-time curves are constructed from seismic data by plotting the source-to-receiver travel time against the source to receiver distance *X*. Exhibit 8.4C-4 is the travel-time curve for a series of horizontal refractors, each of which has a greater seismic velocity than the layer immediately overlying it.

$$t_1 = \frac{X}{V_1} + \frac{2Z_1\,(V_1^2 - V_0^2)^{1/2}}{V_0 V_1} = \frac{X}{V_1} + t_{i1}$$

In Exhibit 8.4C-4 the total time taken by the head wave to propagate through layers 1 and 2 is given by the following equation:

$$Z_1 = \frac{t_{i1}\;V_0 V_1}{2\,(V_1^2 - V_0^2)^{1/2}}$$

This equation describes straight line segment 2 of the travel-time curve, which has slope $1/V_1$ and time intercept $t_{i1}$. The thickness of layer 1 is given by the equation below:

This is also the depth to layer 2.

$$\frac{X_{c1}}{V_0} = \frac{X_{c1}}{V_1} + \frac{2Z_1(V_1^2 - V_0^2)^{1/2}}{V_1 V_0}$$

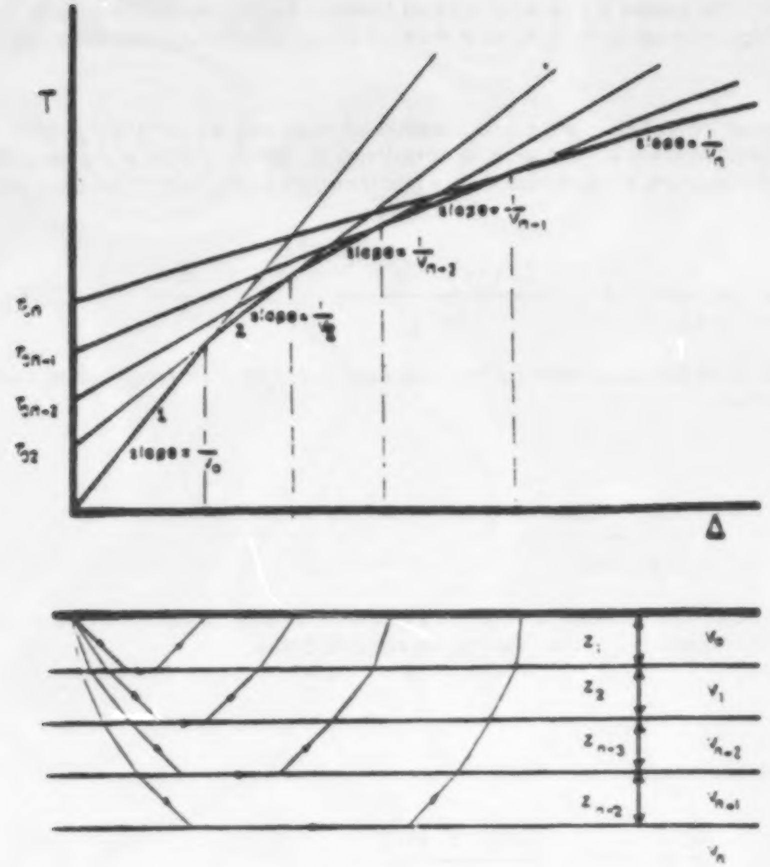
Straight line segments 1 and 2 intersect at point $X_c$, $t_c$; therefore,

$$Z_1 = \frac{X_{c1}}{2}\left[\frac{V_1 - V_0}{V_1 + V_0}\right]$$

and

**Exhibit 8.4C-4**

**RAY PATHS AND TRAVEL-TIME CURVE FOR HORIZONTAL REFRACTORS**


T
$\tau_{n}$
$\tau_{n-1}$
$\tau_{n-2}$
$\tau_{2}$
1
2
slope = $\frac{1}{V_0}$
slope = $\frac{1}{V_2}$
slope = $\frac{1}{V_{n-2}}$
slope = $\frac{1}{V_{n-1}}$
slope = $\frac{1}{V_n}$
Δ
$Z_1$
$Z_2$
$Z_{n-3}$
$Z_{n-2}$
$V_0$
$V_1$
$V_{n-2}$
$V_{n-1}$
$V_n$

This equation uses the critical distance $X_c$ to determine the thickness of layer 1.

The travel-time curve changes significantly for dipping refractors, and the above travel-time depth relations are no longer valid. Reversed seismic profiles yield travel-time curves that reveal dipping refractors. Exhibit 8.4C-5 represents the cross section through a dipping refractor and the reversed travel-time curve associated with it.

$$i_c = \frac{1}{2} \left[ \sin^{-1} \frac{V_0}{V_d} + \sin^{-1} \frac{V_0}{V_u} \right]$$

$$\theta = \frac{1}{2} \left[ \sin^{-1} \frac{V_0}{V_d} - \sin^{-1} \frac{V_0}{V_u} \right]$$

The dip angle $\theta$ and critical angle $i_c$ can be computed from velocities measured from straight line segments of the reversed travel-time curve.

$$\text{(A)} \quad Z_d = \frac{V_0 t_{i1d}}{\cos i_c}$$

The down-dip and up-dip intercept times can then be measured to calculate the down-dip and up-dip

$$\text{(B)} \quad Z_u = \frac{V_0 t_{i1u}}{\cos i_c}$$

thickness of the dipping layer:

and,

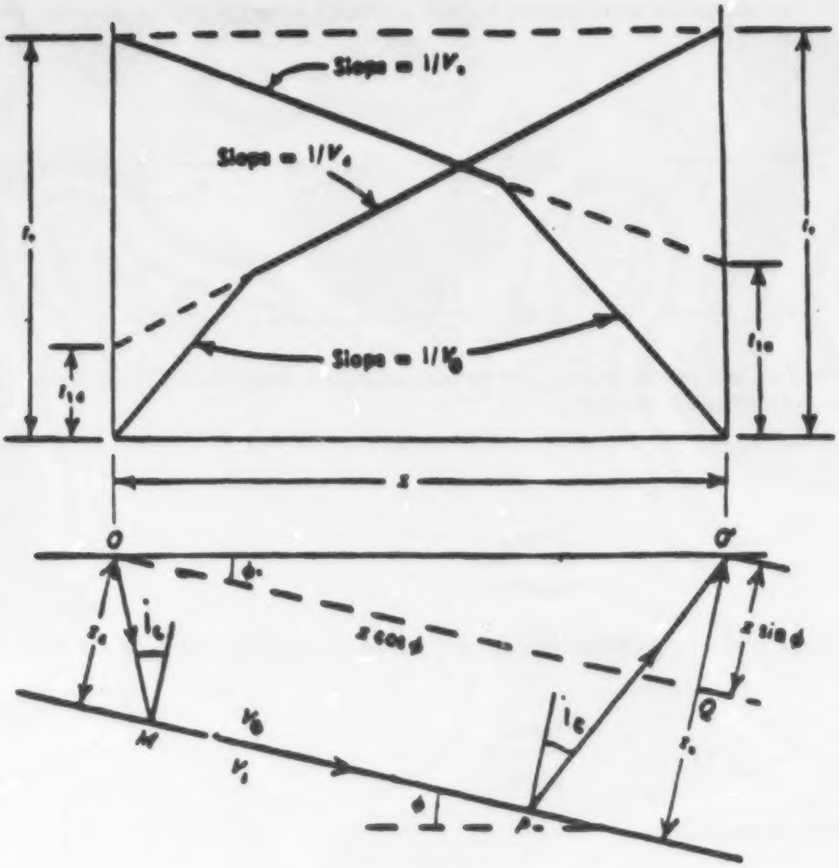
When the dip angle is very small, equations (A) and (B) can be approximated by letting cos of $i_c$ equal 1.

Lateral variations in refractor velocity are manifested in reversed travel-time curves, and examples of some of these situations are illustrated in Exhibit 8.4C-6.

## Seismic Reflection

Refraction time-distance curves for the case of three velocity discontinuities is illustrated in Exhibit 8.4C-7, along with the related set of reflection time-distance curves. The segment of the time-distance curve for rays that are reflected from the bottom of layer "$n$" approaches the straight-line segment of the time-distance curve for rays that are critically refracted from the top of this layer asymptotically at large shot-receiver distances. This similarity is because the ray paths traveled by these rays become identical at

## Exhibit 8.4C-5
## RAY PATH AND TRAVEL-TIME CURVES FOR A DIPPING REFRACTOR


Slope = 1/V₀
Slope = 1/V_d
Slope = 1/V_u
t₀
t₀
t₁d
t₁u
x
O
O'
φ
z_d
i_c
x cos φ
x sin φ
Q
M
V₀
V₁
i_c
z_u
φ
P

SOURCE: Telford et al. (1976).

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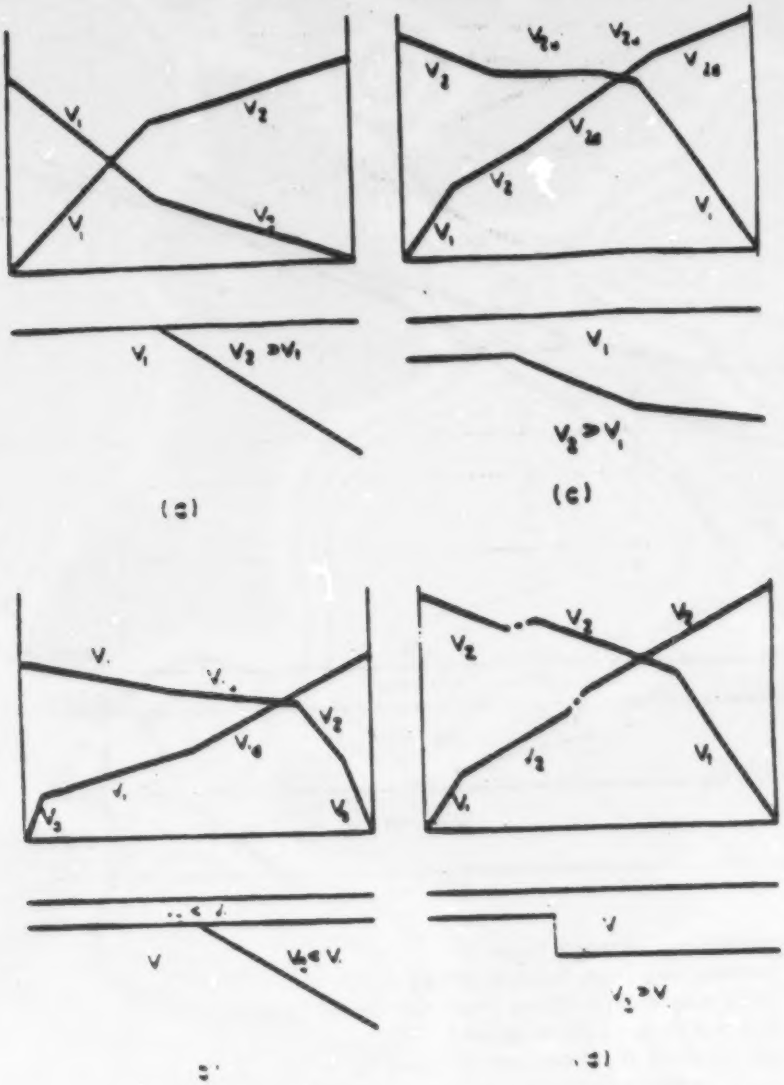
## Exhibit 8.4C-6
## LATERALLY DISCONTINUOUS STRUCTURES AND SCHEMATIC REVERSED REFRACTION TRAVEL-TIME GRAPHS ASSOCIATED WITH THEM



Some examples of simple laterally discontinuous structures and schematic reversed refraction travel-time graphs that would be associated with them. (a) A lateral velocity change. The $t$–$x$ graph is unchanged for any dip of the boundary so long as the higher velocity material overlies the lower. (b) If $V_2 > V_1$, branches of apparent velocities $V_{1d}$, $V_{1u}$ are produced. The effect of an additional low-velocity surface layer is also shown. (c) An increase of refractor dip can also lead to a low velocity branch $V_{2d}$ following one of higher velocity $V_2$. Note that a plane-layer interpretation is possible only if the branches $V_{2u}$–$V_{2d}$ and $V_{2u}$–$V_{2d}$ can be correctly paired. It will usually be easier to use the "plus-minus" approach (eqns. 3.11, 3.12). (d) The dipping segment of (c) is here steepened to a fault-like step. The steps in the $t-x$ graphs are less sharp because of diffraction effects, and are offset

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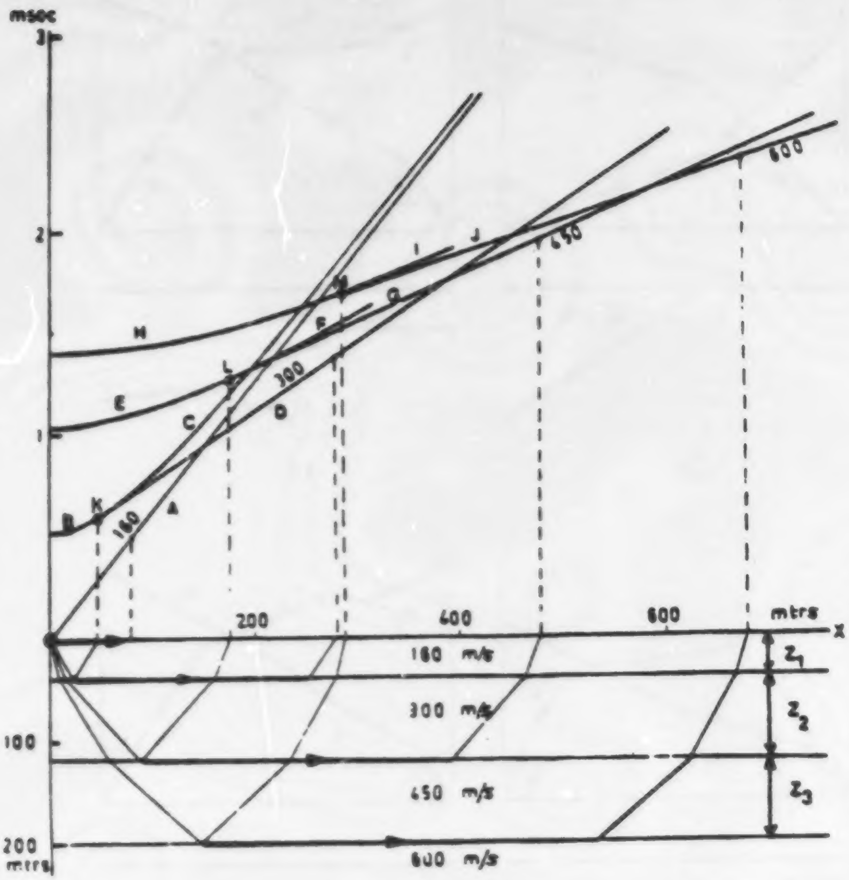
Exhibit 8.4C-7

## REFLECTION-REFRACTION GEOMETRY FOR A FOUR-LAYER CASE



A. Direct ray through layer 1.
B. Reflections from bottom of layer 1.
C. Wide-angle reflections from bottom of layer 1.
D. Refracted rays from layer 2.
E. Reflections from bottom of layer 2.
F. Wide-angle reflections from bottom of layer 2.
G. Refracted rays from layer 3.
H. Reflections from bottom of layer 3.
I. Wide-angle reflections from bottom of layer 3.
J. Refracted rays from layer 4.
K., L., M., Critical distances for layers 1, 2 and 3.

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these distances. The straight-line segment of the time-distance curve for rays critically refracted from the top of the underlying $n + 1$ is tangential to the curve for rays reflected from layer $n$.

At the critical distance $X_{cr}$, travel times for rays reflected from the bottom of layer $n$ equal the travel time for rays critically refracted from the top of the underlying layer $n + 1$. At this distance, rays reflected from the bottom of layer $n$ are reflected at the critical angle. The critical distance for the existence of head waves from a layer is given by the following equation:

$$X_{cr} = 2 Z_n \tan i_c$$

At distances less than $X_{cr}$, no head waves exist from the top of the underlying layer $n + 1$. At distances greater than $X_{cr}$ the head wave from the underlying layer exists and arrives at surface receivers ahead of the ray received at distances greater than $X_{cr}$, which are referred to as "wide angle reflections." Reflected rays from the bottom of layer $n$ undergo a large increase in amplitude near $X_{cr}$ for that layer because of the constructive interference of the head wave refracted from the top of the underlying layer with the reflected ray. Other large increases in the amplitude of the reflected ray occur at crossover points for wide-angle reflections where two or more wide-angle reflections constructively interfere.

In this method, the source-to-receiver travel time of reflection events are squared and plotted against the square of the source-to-receiver distance. Velocity is obtained from the square root of the inverse slope of the straight line segment. The depth to the reflecting layer is obtained from the velocity and time intercept.

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# APPENDIX 8.4D

# MAGNETICS

## THEORY

### Earth's Magnetic Field

A magnetometer measures the intensity of the earth's magnetic field. The earth's magnetic field, or flux lines, resemble the lines of a bar magnet, with the magnetic poles being located near the geographic north and south poles (Exhibit 8.4D-1). The intensity of the magnetic field varies; at the poles it is approximately twice that at the equator, or approximately 60,000 and 30,000 gammas, respectively (Exhibit 8.4D-2).

The inclination of the magnetic field also varies with latitude, being horizontal at the equator and vertical at the poles (Exhibits 8.4D-1 and 8.4D-3). Thus, the intensity of the earth's magnetic field at a given study area is dependent on its location.

At a given location, fluctuations occur in the earth's magnetic field because of effects of the solar wind. Normal diurnal (daily) variations occur in the magnetic field and may be as large as 100 gammas or more. Superimposed on any diurnal variations are short-period micropulsations that are more random in behavior, are generally smaller in amplitude, and may occur at any time. Micropulsations may have durations between 0.1 seconds and several tens of minutes with amplitudes from 0.001 gamma to several tens of gammas. Magnetic storms, causing rapid variation of several hundred gammas in the magnetic field, may occur as often as several days per month and have durations from one to several days.

A recording base station magnetometer is used to make corrections from diurnal variations and for micropulsations, and to identify magnetic storms. The base station is located in an area where representative measurements of the background magnetic field can be obtained on a continuous basis. A magnetometer survey should not be conducted during a magnetic storm. The U.S. National Oceanographic and Atmospheric Administration (NOAA) has regional observatories that monitor the earth's magnetic field and can provide information on the occurrence of magnetic storms.

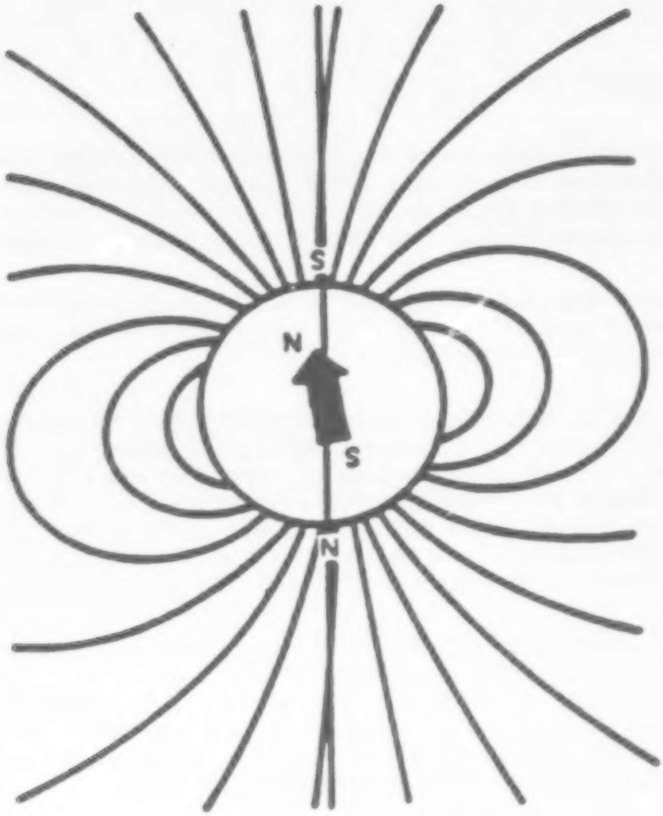
### Types of Portable Magnetometers

Three main types of portable magnetometers are in use:

- Proton precession magnetometer
- Flux gate magnetometer
- Optical-pumping magnetometer

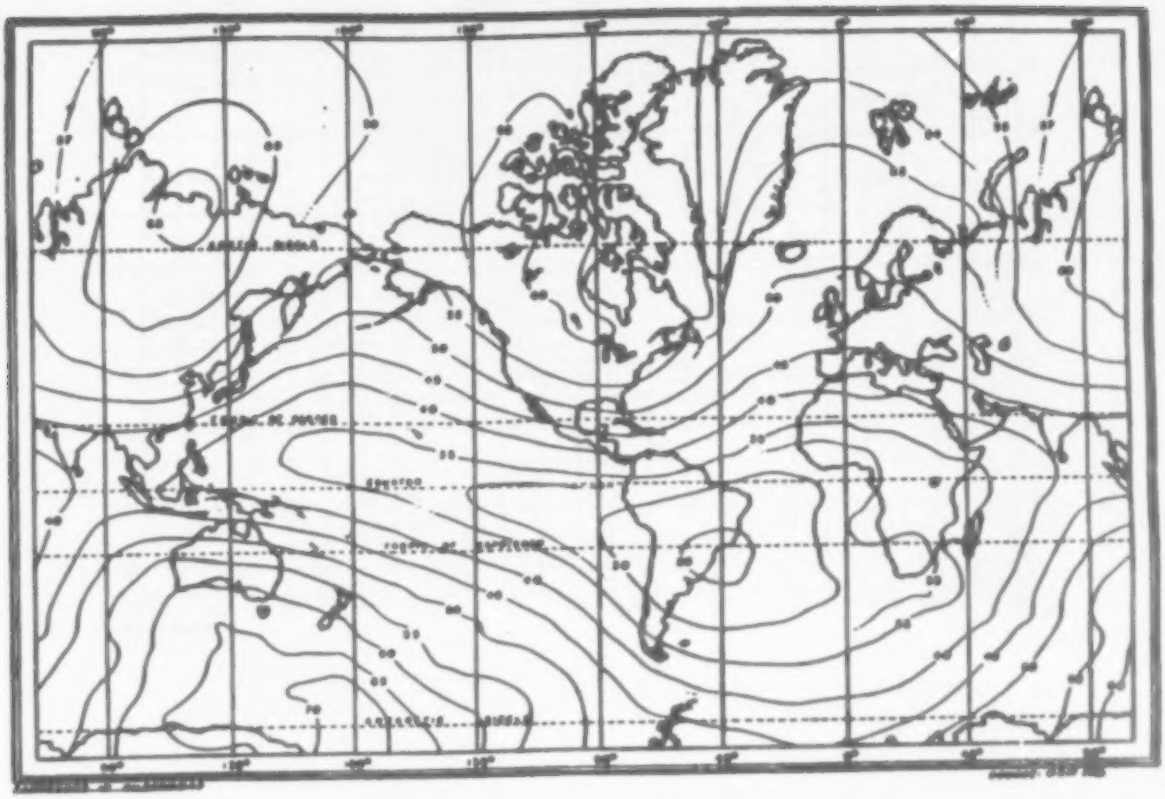
The proton precession magnetometer consists of a coil wound around a bottle of proton-rich fluid, such as water or hydrocarbon fluid. Sufficient current is introduced through the coil to induce within the fluid an external magnetic field about 100 times stronger than the earth's magnetic field. As a result, the magnetic moment of the protons will cause them to align themselves with the new field. When the external field is removed, the magnetic moment of the protons returns, by precession, to its original orientation with

Exhibit 8.4D-1
EARTH'S MAGNETIC FIELD



SOURCE: Breiner (1973).

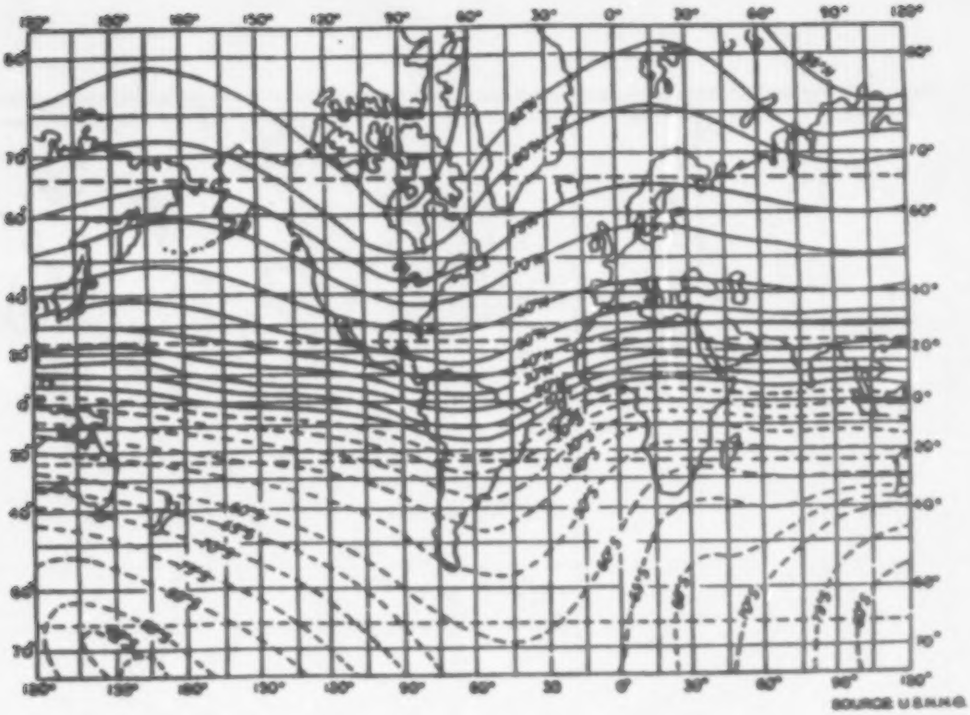
## Exhibit 8.4D-2
## THE TOTAL INTENSITY OF THE EARTH'S MAGNETIC FIELD


ARCTIC CIRCLE
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
ANTARCTIC CIRCLE

NOTE: CONTOURS ARE IN THOUSANDS OF GAMMAS(KILOGAMMAS).

**Exhibit 8.4D-3**

## THE GEOMAGNETIC INCLINATION IN DEGREES OF ARC FROM THE HORIZONTAL


120°
150°
180°
150°
120°
90°
60°
30°
0°
30°
60°
90°
120°
80°
70°
60°
40°
20°
0°
20°
40°
60°
70°

SOURCE: U.S.N.H.O.

**SOURCE:** Breiner (1973).

the earth's field. The precessional oscillation will induce a voltage in a second coil wound around the bottle, and the total field strength is determined by measuring the frequency of the induced voltage. Typical sensitivity for this type of magnetometer is one gamma or better.

The flux-gate magnetometer is used to measure any desired vector component of the earth's magnetic field. This instrument uses a ferromagnetic element of such high susceptibility that the earth's field can induce a magnetization which is a substantial proportion of its saturation value. With a sufficiently large alternating current flowing through a coil around the element, the combined field will saturate the element. For decreasing strength of the earth's field, more current will be required to saturate the element and vice versa. The place in the energizing cycle at which saturation is reached gives a measure of the earth's field. In actual practice, two parallel elements with oppositely wound coils connected in series are employed. The magnetic field component that is parallel to the elements will reinforce the field created by one coil and oppose the field of the other. Typical sensitivity for this type of magnetometer is 10 gammas. Some flux-gate magnetometers provide continuous readings as well as spot readings.

The optical-pumping magnetometer is based on quantum theory. In the absence of a magnetic field, the valence electron of an alkali-metal atom (such as rubidium or cesium) has two states: Level A (the normal level) and Level B (the excited level). In the presence of a magnetic field, Level A splits into two sublevels, A1 and A2. The energy difference between these levels is in the radio frequency range and is proportional to the strength of the magnetic field. By irradiating a gaseous sample of the metal with light from which spectral line A2B has been removed, electrons in Sublevel A2 will not be excited. When the excited electrons fall back to the ground state, they may return to either sublevel, but if they fall to Sublevel A1, they can be removed by excitation to Level B again. The result is an accumulation of electrons in Sublevel A2, and the gaseous sample becomes transparent to the irradiating light beam. This technique of overpopulating one energy level is known as optical pumping. To determine the energy difference between A1 and A2 and, hence, the strength of the magnetic field, radio waves of continually varying frequency are passed through the sample until electrons start moving from A2 to A1 and the optical pumping process is reinitiated. The resumption of optical pumping is indicated by a sharp drop in sample transparency. The energy difference between A1 and A2 can be determined by measuring the corresponding frequency of the radio waves. The optical-pumping magnetometer measures total magnetic field strength with a typical sensitivity of 0.01 gamma.

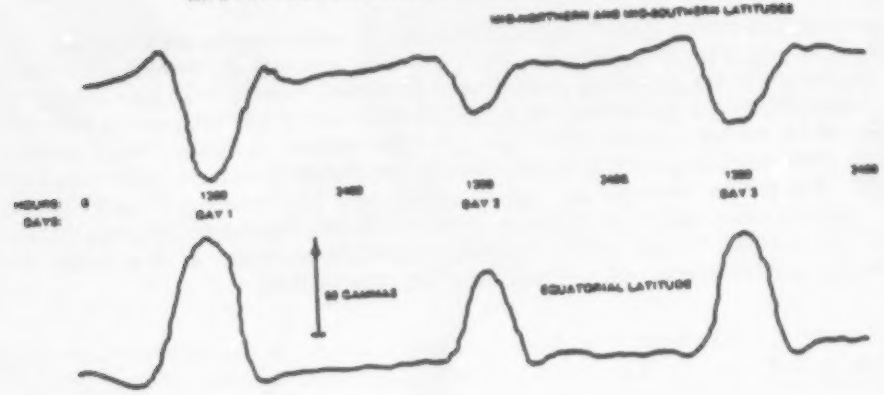
## Base Station

Base stations are one method used to remove diurnal variations from the data. Other methods involve the use of tie-lines. If a base station is used, it should be located in an area free of magnetic anomalies and away from roads, buildings, or other areas where cars may pass or electrical disturbances may occur. The base station location may be screened by taking vertical gradient readings in the area. The vertical gradient at the base station location should be near zero. It is best to have a separate base station magnetometer that will record total field measurements continuously throughout the field survey. Many manufacturers of field and base station magnetometer systems allow for automatic correction for temporal variations in the magnetic field. For automatic recording base stations, a reading interval of 30 seconds to 2 minutes is recommended. If only one magnetometer is available, readings should be obtained at the base station location periodically (i.e., every one-half hour) throughout the field survey.

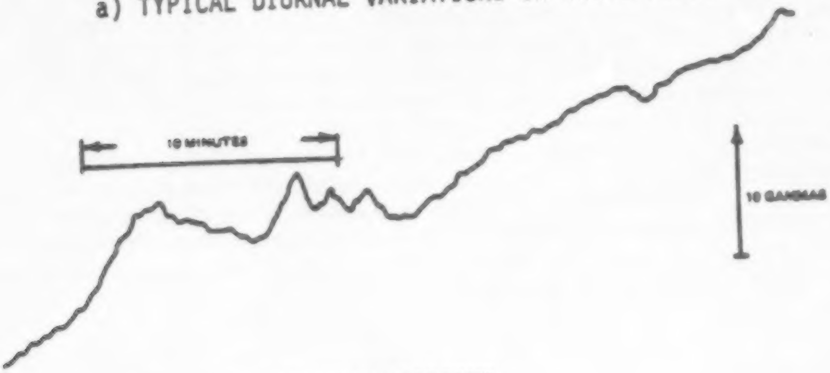
## Correction of Diurnal Variations

Corrections for diurnal variations are made by plotting base station readings on a time-versus-total-field graph (Exhibit 8.4D-4); total-field values for times in between actual readings are interpolated. A datum value for total field is chosen, and the differences ($\Delta T$) between the base station total-field reading and the

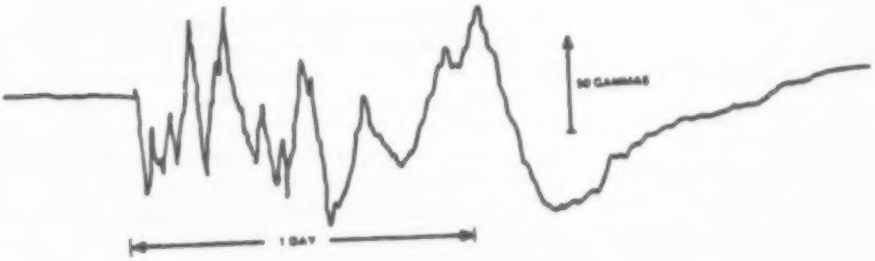
## Exhibit 8.4D-4
## TIME VARIATIONS OF THE EARTH'S TOTAL MAGNETIC FIELD – DIURNAL VARIATIONS, MICROPULSATIONS, AND MAGNETIC STORM



a) TYPICAL DIURNAL VARIATIONS IN TOTAL FIELD INTENSITY



b) TYPICAL MICROPULSATIONS



c) TYPICAL MAGNETIC STORM

SOURCE: Breiner (1973).

datum value can be determined for any time during the survey. The corrected total-field reading for the survey data is obtained by adding $\Delta T$ to the total-field reading.

## Depth Estimates from Total Field

The width of a magnetic anomaly is proportional to the depth (or distance) of the source from the magnetometer sensor; the deeper the source, the broader the anomaly (Exhibit 8.4D-5). This relationship is of primary importance in interpreting the results of a magnetic survey. The proportion between the width of an anomaly and the depth of the source is a function of the fall-off rate, or the variation of anomaly amplitude with distance(d). For a dipole, the total-field anomaly amplitude varies as $1/d^3$, and for a monopole as $1/d^2$. In actual practice, source orientation and other factors may result in fall-off rates from $1/d$ to $1/d^3$. The shape of the magnetic profile of an anomaly and knowledge of the source object help in selecting the proper fall-off rate for depth estimation. A range of depths determined from several fall-off rates may be the most appropriate way to present depth estimates. In general, the anomaly width is on the order of one to three times the depth of the source. Thus, for an anomaly with a width of 100 feet, the source probably lies between 30 and 100 feet deep (or distant). Several methods, including the half- width rule and the slope technique, can be used to estimate source depths from total field profiles.

## Half-Width Rule

The half-width ($x_{1/2}$) of an anomaly on a total field profile is the horizontal distance between the principal maximum (or minimum) of the anomaly (assumed to be over the center of the source) and the point where total field value is exactly one-half of the principal maximum (Exhibit 8.4D-6). A profile that is used for depth estimation by using the half-width rule should be oriented perpendicular to the long axis of the anomaly to give the narrowest profile. This rule is valid only for forms such as spheres, cylinders, and other simple shapes. For example, a single upright 55-gallon steel drum can be approximated as a vertical cylinder (monopole) and the depth ($d$) $= 1.3\,x_{1/2}$. A buried trench filled with drums can be approximated by a horizontal cylinder, where $d = 2\,x_{1/2}$.

## Slope Techniques

Depth of the source can be estimated using the slope of the anomaly at the inflection points of the profile. The horizontal extent ($X_z$) of the "straight" portion of the slope is determined as shown in Exhibit 8.4D-7. The depth is then estimated by the equation,

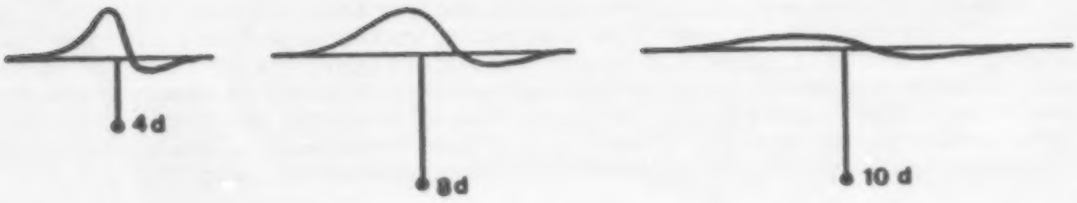
$$d = KX_z \quad \text{where} \quad 0.5 < K < 1.5$$

## Calculation of Magnetic Moment and Mass

$$(1) \qquad T = \frac{M}{d^n}$$

The basic expression for relating anomaly intensity ($T$, in gauss), magnetic moment ($M$, in cgs units), depth ($d$, in centimeters), and the fall-off rate factor ($n$) of a magnetic source object is;

## Exhibit 8.4D-5
## THE EFFECT OF DEPTH ON WIDTH AND AMPLITUDE OF A DIPOLE ANOMALY

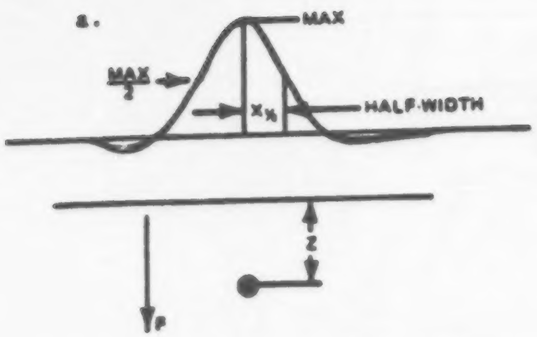


Depth/Amplitude Behavior of Dipole Anomalies

SOURCE: Breiner (1973).

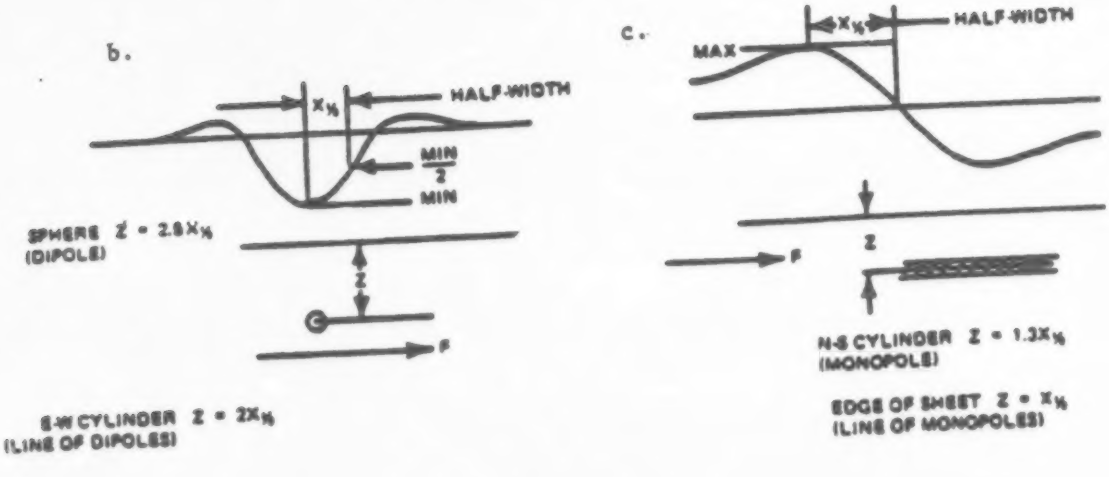
## Exhibit 8.4D-6
## HALF-WIDTH RULES FOR VARIOUS GEOMETRIC SHAPES FOR BOTH VERTICAL AND HORIZONTAL MAGNETIC FIELDS

NOTE: Z = depth


a.
MAX
MAX/2
$X_{1/2}$
HALF-WIDTH
Z
F

| | |
|---|---|
| SPHERE (DIPOLE) | $Z = 2X_{1/2}$ |
| VERTICAL CYLINDER (MONOPOLE) | $Z = 1.3X_{1/2}$ |
| EDGE OF NARROW DIKE (LINE OF MONOPOLES) | $Z = X_{1/2}$ |
| HORIZONTAL CYLINDER (LINE OF DIPOLES) | $Z = 2X_{1/2}$ |

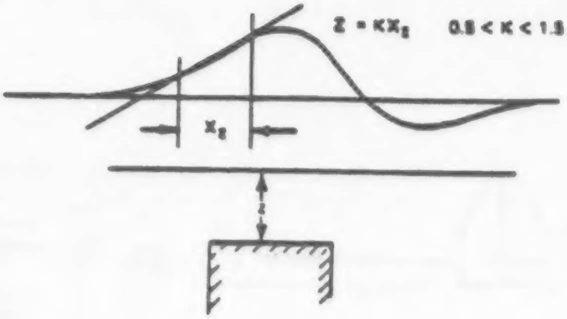
a) HALF-WIDTH RULES - VERTICAL FIELD


b.
$X_{1/2}$
HALF-WIDTH
MIN/2
MIN
SPHERE $Z = 2.8X_{1/2}$ (DIPOLE)
Z
F
E-W CYLINDER $Z = 2X_{1/2}$ (LINE OF DIPOLES)
c.
$X_{1/2}$
HALF-WIDTH
MAX
Z
F
N-S CYLINDER $Z = 1.3X_{1/2}$ (MONOPOLE)
EDGE OF SHEET $Z = X_{1/2}$ (LINE OF MONOPOLES)

b) HALF-WIDTH RULES - HORIZONTAL FIELD (EQUATORIAL)

SOURCE: Breiner (1973).

## Exhibit 8.4D-7
## APPLICATION OF THE SLOPE TECHNIQUE TO A DIPOLE MAGNETIC PROFILE


$Z = KX_s$ $0.5 < K < 1.5$
$X_s$
z

NOTE: Z = depth

SOURCE: Breiner (1973).

## Exhibit 8.4D-8
## MAGNETIC SUSCEPTIBILITIES OF ROCK MATERIALS[1]

| Material | Magnetic Susceptibility ($Kx10^6$, CGS Units) |
|---|---|
| Magnetite | 300,000-800,000 |
| Pyrrhotite | 125,000 |
| Ilmenite | 135,000 |
| Franklinite | 36,000 |
| Dolomite | 14 |
| Sandstone | 17 |
| Serpentine | 14,000 |
| Granite | 28-2,700 |
| Diorite | 46 |
| Gabbro | 68-2,370 |
| Porphyry | 47 |
| Diabase | 78-1,050 |
| Basalt | 680 |
| Olivine-Diabase | 2,000 |
| Peridotite | 12,5000 |

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[1] Adapted from C.A. Helland, "Geophysical Exploration" (from Costello, 1980).

## Depth Estimates from Vertical Gradient

The vertical gradient is the change in total field over a fixed distance. The vertical gradient is the derivative of this equation with respect to distance ($d$):

$$(5) \qquad dT/dd = \frac{-3M}{d^4}$$

Solving equation (1) for $M$,

$$(6) \qquad M = Td^3$$

and substituting equation (6) into equation (5),

$$(7) \qquad dT/dd = \frac{-3Td^3}{d^4} = \frac{-3T}{d}$$

Solving equation (7) for depth (or distance) to the source,

$$(8) \qquad d = \frac{-3T}{dT/dd}$$

Thus, using equation (8), the depth to the source of a (dipole) anomaly can be determined by knowing the anomaly intensity ($T$) above background, and the vertical gradient ($dT/dd$). For a monopole source,

$$(9) \qquad d = \frac{-2T}{dT/dd}$$

In equation (5), note that the fall-off rate for vertical gradient is proportional to $1/d^4$ for dipole, whereas in equation (1), the fall-off rate for total field is proportional to $1/d^3$. This difference explains why vertical gradient measurements provide finer resolution, but less range in detecting anomalies.

Exhibit 8.4D-8 shows magnetic susceptibilities of rock materials.

# APPENDIX 8.4E

# GROUND PENETRATING RADAR

## THEORY

Ground penetrating radar (GPR) systems are similar to electromagnetic (EM) systems in that a source and a receiver are needed. A radar antenna (source) emits an EM pulse several times a second. These EM impulses are then directed into the ground in the form of waves. As the waves penetrate deeper through the geologic material, contrasts in electrical properties are encountered with changes in strata. These electrical contrasts (anomalies) cause some of the wave to be reflected back toward the surface, where it is received by an antenna, while some of the wave continues downward. When enough anomalies have been encountered, there is very little remaining of the signal (to be reflected); this condition is what is termed the effective penetration depth. The time interval between the point when the EM signal is emitted to when it is reflected and received is dependent on the properties of the material and on the depth at which the signal is reflected. The radar impulse travels in water at about 10 percent of the speed of light; in dry sands it travels to as much as 50 percent of the speed of light. Variations in impulse travel speeds are also noticeable when observing a material in a disturbed versus an undisturbed state (less dense). Knowledge of site geology can be used to estimate the properties of the material (and travel time) so that the depth of the target can be determined.

The contrasts in electrical properties are a function of the composition of the materials and moisture contents. Generally, good conductors, such as metal drums, reflect the entire radar signal (EM wave), so there is no penetration below this point. Poor conductors (good resistors), such as unsaturated sands, will generally allow for a deeper radar signal penetration than good conductors such as saturated clays or saline water. For examples of natural variations in resistivity (the opposite of conductivity), the reader should refer to Exhibit 8.4E-1. One possible way to increase penetration is to use a transmitter antenna of lower frequency. The effect of frequency changes upon penetration is an inverse square relationship. As the frequency is doubled, penetration is reduced to one-quarter (but resolution increases).

Typical GPR antennae range in frequency from 10 megahertz (MHz) to 1,000 MHz, with 300 to 600 MHz being considered as standard. The lower the frequency, the larger the antenna, so that some lower-frequency antennae are commonly towed by vehicles, while the higher-frequency ones can be towed by a technician. While lower-frequency antennae permit deeper penetration, they lack the resolution of the higher-frequency antennae. Typical penetration in stratified saturated sands for the 300 MHz antenna is perhaps 50 feet, and for the 600 MHz antenna it is perhaps 25 feet. These depth penetration estimates are for guidance and should be used only for that purpose.

GPR equipment does not sense just straight below the antenna; instead, it senses forward, backward, and to the sides at various angles. For this reason, some objects can be detected without having the equipment pass directly overhead.

## Exhibit 8.4E-1
## NATURAL VARIATIONS IN RESISTIVITY BECAUSE OF MATERIAL AND WATER CONTENT

| Rock Type | Water Content (percent $H_2O$) | Resistivity (ohmmeter) |
|---|---|---|
| Siltstone | 0.54 | $1.5 \times 10^4$ |
| Siltstone | 0.38 | $5.6 \times 10^8$ |
| Coarse Grain Sandstone | 0.39 | $9.6 \times 10^5$ |
| Coarse Grain Sandstone | 0.18 | $10^8$ |
| Graywacke Sandstone | 0.16 | $4.7 \times 10^3$ |
| Graywacke Sandstone | 0.45 | $5.8 \times 10^4$ |
| Dolomite | 2.0 | $5.3 \times 10^3$ |
| Dolomite | 0.96 | $8 \times 10^3$ |
| Peridotite | 0.1 | $3 \times 10^3$ |
| Peridotite | 0 | $1.8 \times 10^7$ |
| Granite | 0.31 | $4.4 \times 10^3$ |
| Granite | 0 | $10^{10}$ |
| Basalt | 0.95 | $4 \times 10^4$ |
| Basalt | 0 | $1.3 \times 10^8$ |
| Olivine-Pyrox. | 0.028 | $2 \times 10^4$ |
| Olivine-Pyrox. | 0 | $5.6 \times 10^7$ |
| Material | | |
| Clays | | 1-100 |
| Sands | | 10 - 800 |
| Sea Water | | 0.2 |
| Groundwater (bedrock) | | 0.5 - 100 |
| Groundwater (overburden) | | 100 |

---

Based on W.M. Telford, et al. Applied Geophysics, 1976.

NOTE: Resistivity is the inverse of conductivity.

## INFORMATION SOURCES

The following list of sources has been categorized into specific groups for easy use.

## Ground Penetrating Radar (GPR)

### Books

Uriksen, P.F. *Application of Impulse Radar to Civil Engineering.* Distributed by Geophysical Survey Systems, Inc. Hudson, New Hampshire. 1982.

### Journals

Morey, R.M. "Continuous Subsurface Profiling by Impulses Radar." Presented at the ASCE Conference--Engineering Foun dation Conference on Subsurface Exploration for Underground Excavation and Heavy Construction. 1974.

Wright, D.L., G.R. Olhoeft, and R.D. Watts. "Ground- Penetrating Radar Studies on Cape Cod." Denver Federal Center, Colorado: U.S. Geological Survey. 1983.

### GPR General Manuals

Benson, R.C., R.A. Glaccum, and M.R. Noel. *Geophysical Techniques for Sensing Buried Wastes and Waste Migration.* Prepared by Technos, Inc., for the U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory. Las Vegas, Nevada. 1983.

Costello, R.L. *Identification and Description of Geophysical Techniques.* Prepared by D'Apollonia for U.S. Army Toxic and Hazardous Materials Agency. Aberdeen Proving Ground, Maryland. 1980.

### Manufacturers

Geophysical Survey Systems, Inc. 15 Flagstone Drive Hudson, New Hampshire 03051

# APPENDIX 8.4F

# BOREHOLE GEOPHYSICS

## INFORMATION SOURCES

### Borehole Theory and Interpretation

Costello, R.L. *Identification and Description of Geophysical Techniques.* Prepared by D'Apollonia for the U.S. Army Toxic and Hazardous Materials Agency. 1980.

Dresser Industries. *Log Interpretation Fundamentals.* Houston, Texas. 1975. 125 pp.

Keys, W.S., and L.M. MacCary. "Application of Borehole Geophysics to Water-Resources Investigations." *Techniques of Water-Resources Investigations of the United States Geological Survey.* Chapter El, Book 2. Washington, D.C.: U.S. Government Printing Office. 1971.

Pirson, S.J. *Handbook of Well Log Analysis.* Englewood Cliffs, New Jersey: Prentice-Hall. 1963.

Sammel, E.A. "Convective Flow and Its Effect on Temperature Logging in Small-Diameter Wells." *Geophysics.* Vol. 33, No. 6, pp. 1004-1012. 1968.

Schlumberger Limited. *Log Interpretation.* Vol. 1. New York, New York. 1972.

Schlumberger Limited. *Log Interpretation.* Vol. 2. New York, New York. 1974.

Telford, W.M., L.P. Geldart, R.F. Sheriff, and D.A. Keyes. *Applied Geophysics.* Pp. 774-781. Binghamton, New York: Vail-Ballou Press, Inc. 1980.

Wheatcraft, S.W., J.W. Hess, and W.M. Adams. *Equipment and Techniques Applicable to Subsurface Sensing and Monitoring at Hazardous Waste Sites.* U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Office of Research and Development. Las Vegas, Nevada.

U.S. Bureau of Mines. "Calibration Models for Geophysical Borehole Logging." USBM RI 8148. Washington, D.C.: U.S. Department of the Interior. 1976. 21 pp.

U.S. Geological Survey. "Application of Electrical and Radioactive Well Logging to Ground Water Hydrology." Geological Survey Water Supply Paper 1544-D. Washington, D.C.: U.S. Government Printing Office. 1963. 60 pp.

U.S. Geological Survey. "Methods of Flow Measurement in Well Bores." Geological Survey Water-Supply Paper 1544-C. Washington, D.C.: U.S. Government Printing Office. 1962. 28 pp.

## Borehole Logging Instrument Manufacturers

Comprobe, Inc.
9632 Crowley Road
Crowley, Texas 76036
817/293-7333

Gearhart-Owen
P.O. Box 1936
Fort Worth, Texas 76101
817/293-1300

Geotronic Corporation
10317 McKalla Place
Austin, Texas 78758

McPhar Geophysics
55 Tempo Avenue
Willowdale, Ontario M2H 2R9
416/497-1700

Mount Sopris Instrument Company
P.O. Box 449
Delta, Colorado 81416
303/874-4852

## 8.5 GROUNDWATER MONITORING

### 8.5.1 Scope and Purpose

This subsection provides general information on equipment and materials used in groundwater monitoring programs.

### 8.5.2 Definitions

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

All other terms in this subsection are in common usage.

### 8.5.3 Applicability

Almost every investigation of hazardous waste sites entails groundwater sampling and monitoring. Since each site is different, experienced hydrogeologists and geochemists should be consulted to establish the most suitable type of monitoring for a particular site. Monitoring well placement and sampling requirements for each site are detailed in a site-specific sampling plan. The procedures described below have all been used successfully on hazardous waste sites.

### 8.5.4 Responsibilities

The SM is responsible for determining the type and placement of groundwater monitoring networks. The SM is assisted by experienced hydrogeologists and geochemists. As discussed earlier in Section 8, an experienced hydrogeologist will supervise the installation of monitoring wells.

### 8.5.5 Records

Field notes are kept in a bound, weatherproof logbook. Entries are made chronologically in indelible ink on numbered pages, with the date, time, and notetaker's initials recorded for each entry. Certain forms used in groundwater monitoring are discussed in the following subsections and in Sections 3, 4, 5, and 17 of this compendium.

### 8.5.6 Procedures

#### 8.5.6.1 Water Wells

Production or traditional wells are often used to obtain samples in ambient groundwater monitoring programs. Designed to yield large quantities of turbidity-free water for potable or irrigation supplies, these wells generally tap the more permeable portions of an aquifer. They may be screened in unconsolidated material. Chemical data obtained from these wells depict the quality of water being delivered to the user community. Because water pumped from these wells is often a composite of water from different strata in the aquifer systems, the presence of relatively narrow or small plumes of polluted water may be masked by dilution with water obtained from unaffected portions of the aquifer.

Production or traditional wells should not be used for the more detailed source, case-preparation, and research types of monitoring. Such detailed monitoring efforts call for wells designed to determine the groundwater quality at a given location and depth within the geologic materials being monitored. All available geologic and hydrologic information for the site of interest should be reviewed prior to the selection of preliminary locations and depths for monitoring wells. The potential paths of pollutant movement from the site should be estimated, and wells should be placed to define contaminant plumes. Information gained during the drilling process should be used to modify the monitoring plan to make it more effective.

### 8.5.6.1.1 Monitoring Well Components

The principal reason that monitoring wells are constructed is to collect groundwater samples that, upon analysis, can be used to delineate a contaminant plume and track movement of specific chemical or biological constituents. A secondary consideration is the determination of the physical characteristics of the groundwater flow system to establish flow direction, transmissivity, quantity, etc. The spatial and vertical locations of monitoring wells are important. Of equal importance are the design and construction of monitoring wells that will provide easily obtainable samples and yield reliable, defensible, meaningful information. In general, monitoring well design and construction follow production well design and construction techniques. However, emphasis is placed on the effect these practices may have on the chemistry of the water samples being collected rather than on maximizing well efficiency.

From this emphasis, it follows that an understanding of the chemistry of the suspected pollutants and of the geologic setting in which the monitoring wells are constructed plays a major role in determining the drilling technique and materials used.

There are several components to be considered in the design of a monitoring well including location, diameter, depth, casing, screen, sealing material, and well development. As these components are discussed in detail, it may be helpful to refer to Exhibit 8.5-1, which portrays two typical well installations: one for water supply and the other for groundwater quality monitoring.

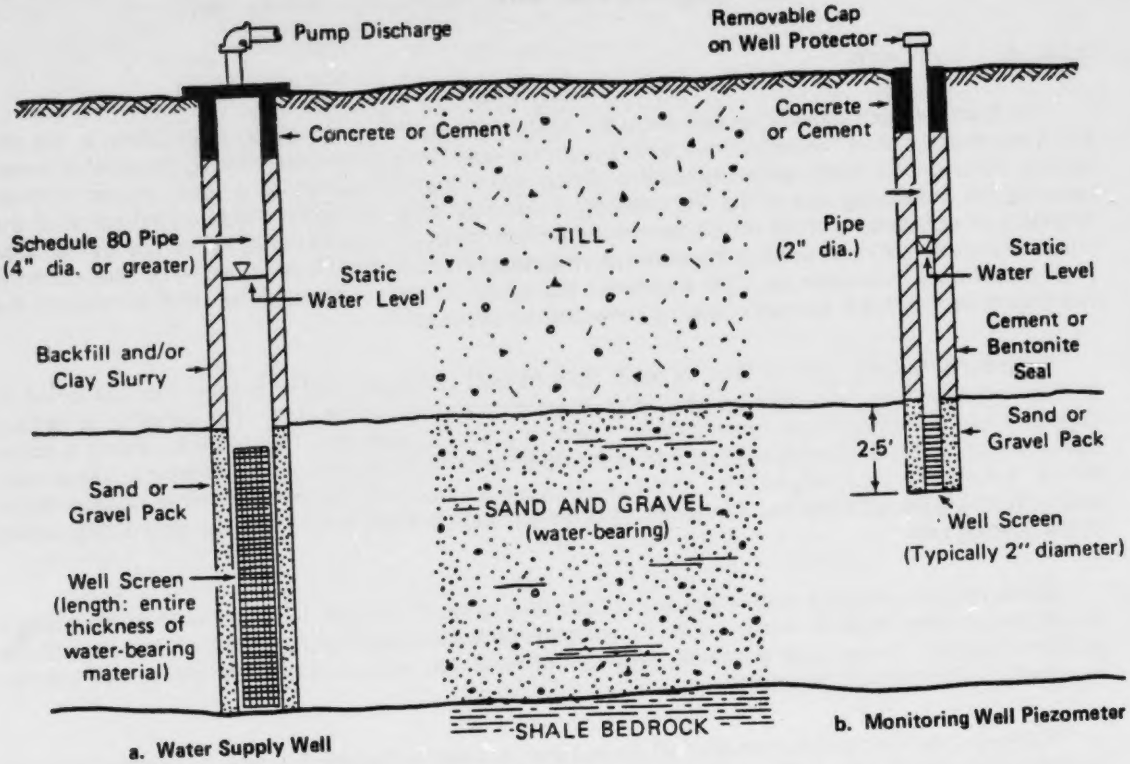
### 8.5.6.1.2 Well Location

The location of a monitoring well should be selected on the basis of the purpose of the sampling effort. This purpose may be to verify predictions of contaminant migration; to detect contaminants in drinking water supplies and thus to protect public health; to activate a contingency plan, such as a program for leachate collection; to protect the operator; to reassure the public by demonstrating that water quality is being monitored; or to define a contaminant plume. Each of these purposes will require a somewhat specialized array of monitoring points and a somewhat different sampling program as defined by the project sampling plan. The monitoring system must be designed to suit the purpose(s) in mind.

### 8.5.6.1.3 Well Diameter

A domestic water supply well is commonly 4 or 6 inches in diameter to accommodate a submersible pump capable of delivering 5 to 10 gallons per minute (gpm). Centrifugal and jet pumps are also used. Municipal and industrial supply wells have greater diameters to handle larger pumps for greater pumping capacity. As in water supply wells, the diameter of a monitoring well is largely determined by the size of the sampling device or pump. Pumping one or more well volumes of water from a large-diameter monitoring well may present a problem, because large quantities of water must be disposed of or contained. With the

## Exhibit 8.5-1
## TYPICAL INSTALLATIONS OF (a) WATER SUPPLY WELLS AND (b) MONITORING WELLS


Pump Discharge
Concrete or Cement
Schedule 80 Pipe (4" dia. or greater)
Static Water Level
Backfill and/or Clay Slurry
Sand or Gravel Pack
Well Screen (length: entire thickness of water-bearing material)
TILL
SAND AND GRAVEL (water-bearing)
SHALE BEDROCK
Removable Cap on Well Protector
Concrete or Cement
Pipe (2" dia.)
Static Water Level
Cement or Bentonite Seal
Sand or Gravel Pack
2-5'
Well Screen (Typically 2" diameter)
a. Water Supply Well
b. Monitoring Well Piezometer

advent of several commercially available small-diameter pumps (less than 2 inches outside diameter) capable of lifting water from several hundred feet, it is rarely necessary to construct monitoring wells larger than 2 inches in diameter. Additionally, the smaller the diameter, the less it will cost for drilling and construction. Small diameter wells with corresponding low-volume pumps may be preferable for sampling for volatile organics, because they create less turbulence and provide a sample that is more representative of aquifer conditions. Monitoring wells in high-transmissivity aquifers may be larger than 2 inches in diameter if pumping test methods are used to determine aquifer characteristics. Larger diameter, high-capacity pumps are needed to conduct pumping tests; these pumps require larger diameter wells.

### 8.5.6.1.4 Well Depth

The depth of each monitoring well is usually determined by the geohydrologic conditions at the site being monitored. Most "detective" monitoring wells are completed in the first relatively permeable water-bearing zone encountered, since potential pollution sources are frequently at or near ground surface. Locating the monitoring well in the first relatively permeable zone, therefore, yields an indication of the migration of pollutants in most situations. However, care must be taken to ensure that the well is completed at a depth sufficient to allow for seasonal water table fluctuations. Under confined or semi-confined (leaky) conditions, the water level will rise above the top of the water-bearing zone. In this instance, the well should be finished in the water-bearing zone and not above it.

If the water-bearing zone is thick (greater than 10 feet) or contamination is known or suspected in deeper formations, multiple wells completed at different depths should be used. For sampling at various depths, some geologists have nested several wells in a single borehole. This requires drilling a large-diameter hole and exercising special care to ensure that the vertical integrity of the sampling points is maintained. It may be more costly to drill separate wells, but the reduction of potential for cross contamination often offsets the added expense. Formation samples (cuttings or core) would be taken only during boring of the deepest well.

Where multiphase or nonaqueous phase liquids are suspected at a site, multilevel wells within a single aquifer may also be needed. For example, if oil or gasoline is the contaminant, monitoring at the top of the aquifer is needed. In contrast, sites with "sinking" contaminants, such as trichloroethylene, may warrant monitoring at the base of the aquifer.

Monitoring wells should be constructed so that they are depth discrete (i.e., able to sample from one specific formation or zone without interconnection to others). Where multiple aquifers exist, it may be desirable to set multiple casing strings to ensure isolation of deeper aquifers from shallow, potentially contaminated ones. This procedure, called telescoping, is identical to that used in the oil and gas business and necessitates the setting and cementing of successively smaller diameter casing strings until the target aquifer is reached. Care must be taken with each casing string to cement with returns to surface to ensure no interconnection between aquifers. Grout can be placed above and, if necessary, below the intake portion of the well to make it depth-discrete.

### 8.5.6.1.5 Well Design and Construction Materials.

The type of material used for monitoring well casing may have a distinct effect on the quality of the water samples collected. Galvanized casing will impart iron, manganese, zinc, and cadmium to many waters. Steel casing may impart iron and manganese to the water samples. Polyvinyl chloride (PVC) pipe has been shown to release and absorb trace amounts of various organic constituents to water after prolonged exposure. PVC solvent cements used to attach sections of PVC pipe have also been shown to release significant quantities of organic compounds. Teflon and glass are among the most inert materials that have been considered for monitoring well construction. Glass, however, is very difficult and expensive to use under most field conditions. Stainless steel has also been found to work satisfactorily under most monitoring conditions. Fiberglass-reinforced plastic has recently been used at sites where organic contaminants are present. This material is not as expensive as stainless steel and does not have as strong a tendency to sorb or release contaminants as PVC does. A detailed discussion of materials is presented in later portions of the text.

All well screens should allow free entry of water. They should also produce clear, silt-free water. This is especially important with regard to drinking water supplies, because sediment in the raw water can create additional pumping and treatment costs and can lead to the general unsuitability of the finished water. Also, in monitoring wells, sediment-laden water can greatly lengthen filtering times and create chemical interferences with the collected samples.

Commercially manufactured well screens generally work best provided the proper slot size is chosen. In formations where fine sand, silt, and clay predominate, sawed or torch-cut slots will not retain the material, and the well may clog. If practical, it may be helpful to have well screens of several slot-sizes available onsite so that the correct screen can be placed in the hole after the water-bearing materials have been inspected. The use of sawed or torch-cut slotted screens is not recommended; indeed, most EPA regions do not permit the use of such screens. Customized screens limit the reproducibility of data. Gravel-packing materials compatible with the selected screen size and aquifer grain size will further help retain fine materials and will also allow freer entry of water into the well by creating a zone of higher permeability around the well. The backfill material must be free of contaminants.

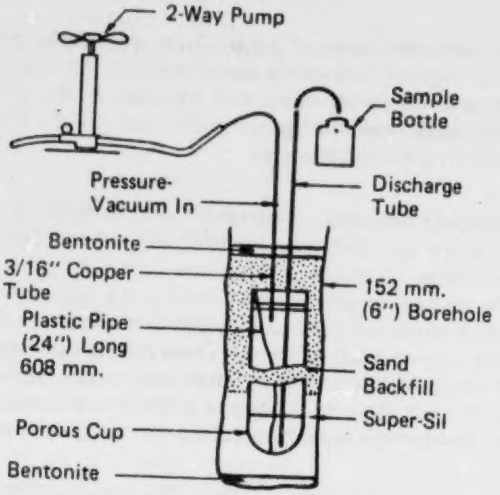
Well screen length is an important consideration. The transmissivity of the aquifer will be used to establish the length of screen. Low yield aquifers may require greater screen lengths to permit the collection of adequate sample volumes in a timely manner. A monitoring program to describe contaminant plume geometry requires the sampling of discrete intervals of the water-bearing formation. In this situation, screen lengths of no more than 5 feet (1.5 m) should be used. Thick aquifers would require completion of several wells at different depth intervals. In some situations, only the first water-bearing zone encountered will require monitoring. Here the "aquifer" may be only 6 inches to a few feet (0.2 to 2 m) thick, and the screen length should be limited to 1 or 2 feet (less than 1 m). In other circumstances where an aquifer with a potable water supply is monitored, the entire thickness of the water-bearing formation should be screened to provide an integrated water sample comparable to that found in the drinking water supply. Monitoring for low-density organic solvents or hydrocarbons that may float on the surface of the water creates a special problem. In such a case, the screen must be long enough to extend above the water level in the formations so that these lighter substances can enter the well. Some companies have developed probes or samplers that can be placed in a single borehole to monitor several zones simultaneously. The units are limited to low flow conditions, which necessitates longer sampling times. However, the low cost of installation of these units (techniques are similar to monitoring well installation) can be a factor in selecting these devices.

It is critical that the screened portion of each monitoring well have access to the groundwater from a specific depth interval. Vertical movement of water in the vicinity of the intake and around the casing must be prevented to obtain samples representative of the formation of interest. Specifically, rainwater can infiltrate backfill materials and dilute or contaminate samples collected from the screened portion of the well. Vertical seepage of leachate or contaminated water from adjacent formations along the well casing may also produce unrepresentative samples for the depth interval being sampled. More importantly, the creation of a conduit in the annulus of a monitoring well that could contribute to or hasten the spread of contamination should be avoided.

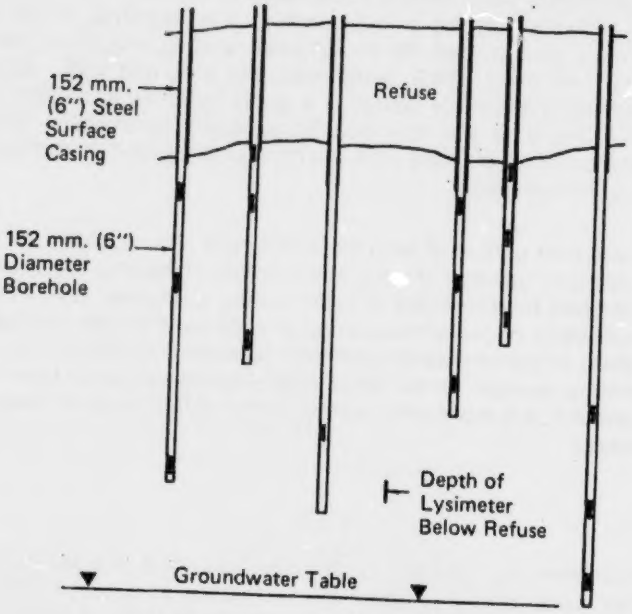
### 8.5.6.2 Lysimeters

Pressure-vacuum lysimeters may be used to obtain samples of in situ soil moisture. They are used predominantly in the unsaturated zone (i.e., above the water table, as shown in Exhibit 8.5-2). In its most improved form, this device consists of a porous ceramic cup capable of holding a vacuum, a small-diameter sample accumulation chamber of PVC pipe, and two sampling tubes leading to the surface.

## Exhibit 8.5-2
## PRESSURE-VACUUM LYSIMETER INSTALLATION


2-Way Pump
Sample Bottle
Pressure-Vacuum In
Discharge Tube
Bentonite
3/16" Copper Tube
152 mm. (6") Borehole
Plastic Pipe (24") Long 608 mm.
Sand Backfill
Super-Sil
Porous Cup
Bentonite

Cross Section of a Typical Pressure-Vacuum Lysimeter Installation


152 mm. (6") Steel Surface Casing
Refuse
152 mm. (6") Diameter Borehole
Depth of Lysimeter Below Refuse
Groundwater Table

Cross Section of a Lysimeter Network

Once the lysimeter is in place, a vacuum is applied to the cup. Soil moisture moves into the sampler under this gradient, and a water sample gradually accumulates. Care must be taken in using samples from suction lysimeters for water quality assessments. The application of the vacuum to drive the water may remove volatile organics or alter carbonate chemical equilibrium. When the vacuum is released and inert gas pressure is applied, the accumulated water is forced to the surface through the sampling tube. A typical pressure-vacuum lysimeter installation is shown in Exhibit 8.5-2.

### 8.5.6.3 Piezometers and Tensiometers

The terms "piezometer" and "observation well" are commonly used interchangeably; however, there is a significant difference between them. As implied by its name, a piezometer is a pressure-measuring device that is frequently used for monitoring water pressure in earthen dams, under foundations, or in aquifers.

A piezometer that is used to monitor earthen dams or foundations resembles a porous tube or plate. A piezometer that is used to monitor aquifers resembles a screened well or open hole. An impermeable clay or cement seal isolates the piezometer from other pressure environments. If the well screen is properly isolated by an impermeable seal placed immediately above the screen, a piezometer can also be used to measure vertical head differences under unconfined conditions. Any well constructed without this seal cannot be considered a piezometer. In practice, piezometers are similar to the monitoring wells described in Subsection 8.5.6.1. If the well is going to be used only for water level measurements, it is generally called a piezometer. In that case, well construction materials are less critical.

Piezometers are not suitable for the measurement of pressure above the water table since water in the unsaturated zone is held in the soil pores under surface-tension forces. The pressure head in the unsaturated zone is called the tension head or suction head. Tensiometers are used to indirectly measure the pressure head in the unsaturated zone to help determine the groundwater gradients and the flow in the unsaturated zone.

Typically, a tensiometer consists of a porous cup attached to an airtight, water-filled tube. The porous cup is inserted into the soil at the desired depth, where it comes into contact with the soil water and reaches hydraulic equilibrium. The equilibrium process involves the passage of water through the porous cup from the tube into the soil. The vacuum created at the top of the airtight tube is a measure of the pressure head in the soil. The pressure head is usually measured by a vacuum gauge attached to the tube above the surface of the ground. To obtain the hydraulic head, the negative value indicated by the vacuum gauge on the tensiometer must be added algebraically to the elevation of the point of measurement. In practice, the tensiometer is a tube with a gauge and a porous cup at the base; the piezometer is an open pipe with a well point at the base.

### 8.5.6.4 Groundwater Sampling Equipment

The type of system used to collect groundwater samples is a function of the type and size of well construction, pumping level, type of pollutant, analytical procedures, and presence or absence of permanent pumping fixtures. Ideally, sample withdrawal mechanisms should be completely inert; economical to manufacture; easily decontaminated, cleaned, and reused; able to operate at remote sites in the absence of external power sources; and capable of delivering continuous but variable flow rates for flushing and sample collection.

Most water supply wells contain semi-permanently mounted pumps that limit the options available for groundwater sampling. Existing in-place pumps may be line shaft turbines, commonly used for high-capacity wells; submersible pumps commonly used in domestic wells for high-head, low-capacity applications and, more recently, for municipal and industrial uses; and jet pumps commonly used for shallow, low-capacity domestic water supplies. The advantages of in-place pumps are that water samples are readily available and that nonrepresentative stagnant water in the well bore is generally not a problem. The disadvantage is that excessive pumping can dilute or increase the contaminant concentrations so that they are not representative of the sampling point. Another possible disadvantage is that water supply wells may produce water from more than one aquifer and contamination or adsorption may be a problem when sampling for organics.

The advantage to collecting water samples from monitoring wells without in-place pumps lies in the fact that the selection of equipment and procedures is flexible. The principal disadvantage lies in the possibility of obtaining a nonrepresentative sample either through collecting stagnant water that is in the well bore or through introducing contamination from the sampling equipment or procedures. Some commonly used sampling systems are described below.

### 8.5.6.4.1 Bailers

One of the oldest and simplest methods of sampling water wells is the use of bailers. A bailer may be a weighted bottle, a capped length of pipe on a rope, or some modification thereof that is lowered and raised, generally by hand. Two examples are the modified Kemmerer sampler and the Teflon bailer represented in Exhibits 8.5-3 and 8.5-4. The modified Kemmerer sampler is more often used for sampling surface water than groundwater. The Teflon bailer was developed specifically for collecting groundwater samples for volatile organic analysis. Bailers are also made of PVC, copper, or stainless steel. The sampling plan will specify equipment, materials, and procedures used in sampling. The material best-suited to the purpose of the project should be selected.

The advantages of using a bailer are as follows:

- A bailer can be constructed from a wide variety of materials that are compatible with the parameter of interest.
- It is economical and convenient enough that a separate one may be dedicated to each well to minimize cross contamination.
- It does not require an external power source.
- Its low surface-to-volume ratio reduces outgassing of volatile organics.

The following are disadvantages of using a bailer:

- It is sometimes impractical to evacuate stagnant water in a well bore with a bailer.
- An open-top bailer may allow nonaquifer material to enter the bailer as it is withdrawn from the well (i.e., rust from casings).
- The transfer of a water sample from the bailer to the sample bottle can result in aeration.
- Cross contamination can be a problem if bailers are not adequately cleaned after each use.
- Care must be exercised in handling the bailer rope to prevent introducing contamination into the well.

## Exhibit 8.5-3
## MODIFIED KEMMERER SAMPLER

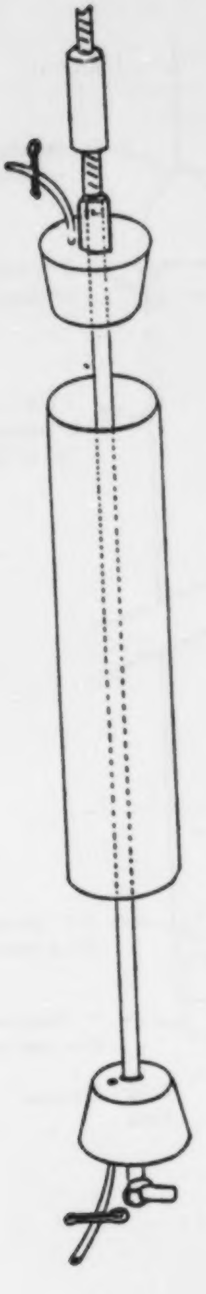
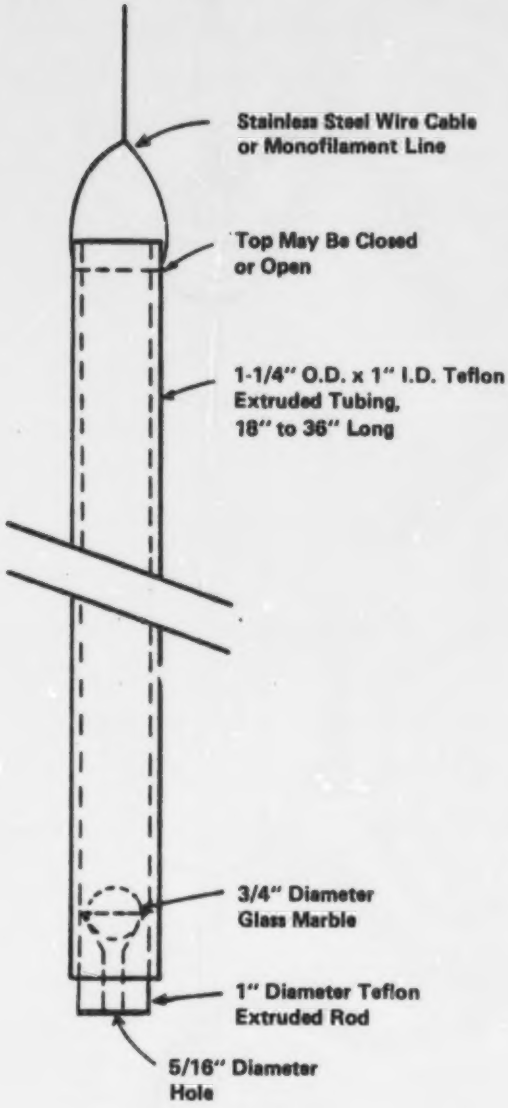


**Exhibit 8.5-4**
**TEFLON BAILER**


Stainless Steel Wire Cable
or Monofilament Line
Top May Be Closed
or Open
1-1/4" O.D. x 1" I.D. Teflon
Extruded Tubing,
18" to 36" Long
3/4" Diameter
Glass Marble
1" Diameter Teflon
Extruded Rod
5/16" Diameter
Hole

### 8.5.6.4.2 Suction-Lift Pumps

A variety of pumps can be used to flush wells prior to sampling or, in limited instances, to obtain samples. When the water table is about 20 to 28 feet from the surface, a suction-lift pump can be used. Centrifugal pumps are the most commonly available type of suction-lift pump, are highly portable, and have a pumping rate of from 5 to 40 gpm. Most centrifugal pumps require a foot valve on the end of the suction pipe to aid in maintaining a prime.

Peristaltic pumps are generally low-volume suction pumps suitable for sampling shallow, small-diameter wells. Their pumping rates are generally low but can be readily controlled within desirable limits. The low pumping rates are a significant limitation in flushing out the well bore. Another limitation is that electrical power is required.

Hand-operated diaphragm pumps are available that can be operated over a wide range of pumping rates, which facilitates rapid evacuation of a well bore initially and provides lower controlled pumping rates for subsequent sampling. One major advantage of such pumps is their portability. A disadvantage is that sampling is limited to groundwater situations where water levels are less than about 20 feet.

Suction pumps are not recommended because they may cause degassing, pH modification, and loss of volatile compounds.

### 8.5.6.4.3 Portable Submersible Pumps

Groundwater investigations routinely require the collection of samples from depths that exceed the capabilities of the systems discussed above. One alternative system consists of a submersible pump that can be lowered or raised in an observation well, using as much as 300 feet of hose that supports the weight of the pump, conveys the water from the well, and houses the electrical cable and an electrical winch-and-spool assembly. A portable generator provides electricity for both the pump and the winch, and the entire assembly can be mounted in a pickup or van.

The following are advantages of using submersible pumps:

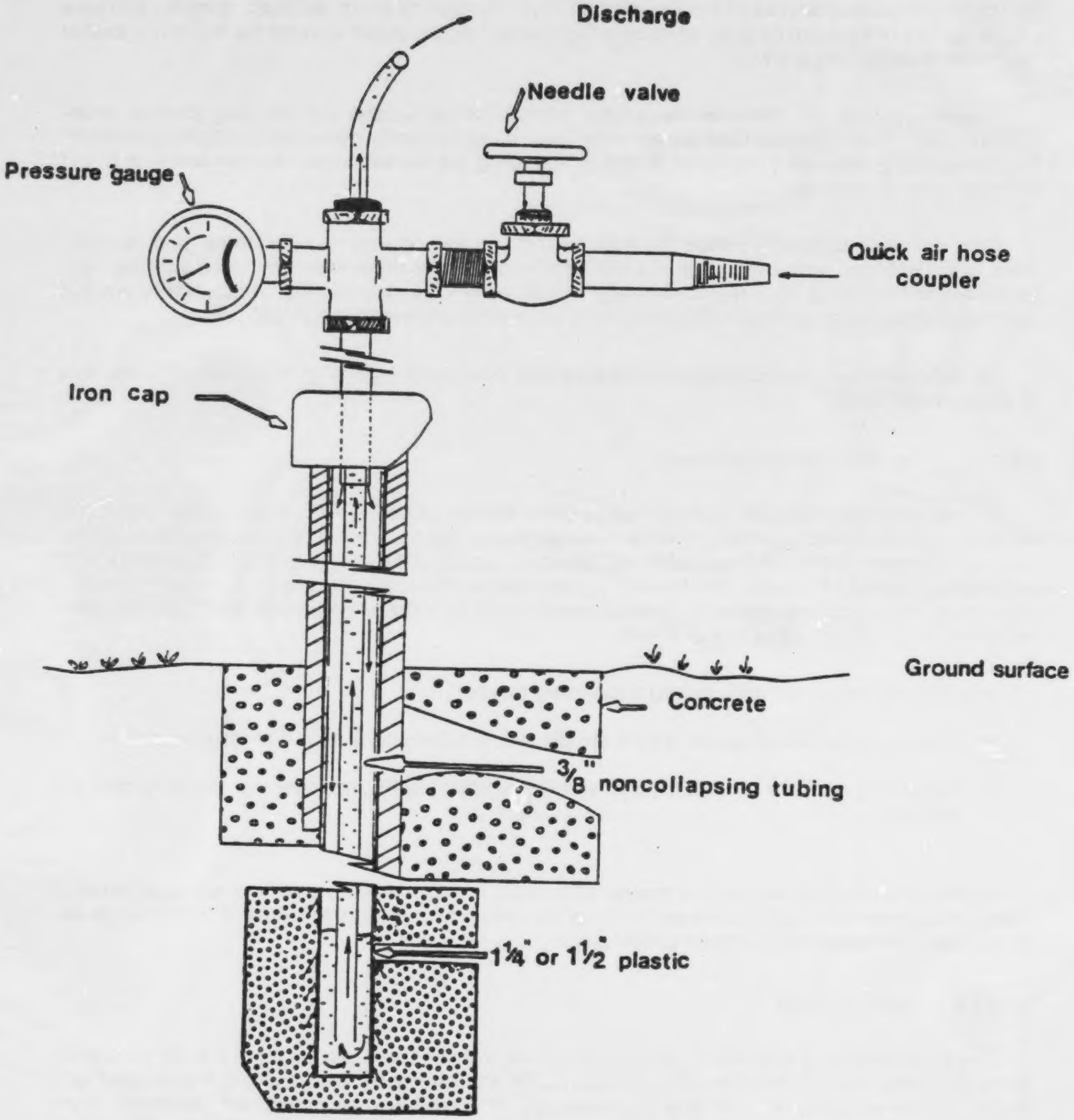
- They are portable and can be used to sample several monitoring wells in a brief period of time.
- Depending upon the size of the pump and the pumping depths, relatively high pumping rates are possible.

Existing bladder-type submersible pumps will operate in 2-inch monitor wells and are constructed of materials to permit water quality samples from monitor wells. The pumps require dedication to a single well or vigorous decontamination between sampling sites.

### 8.5.6.4.4 Air-lift Samplers

The basic method of applying air pressure to a water well can be adapted to force a water sample out of the discharge tube. A high-pressure hand pump and any reasonably flexible tubing can be used as a highly portable sampling unit. A small air compressor or compressed air cylinder and somewhat more elaborate piping arrangements may be required at greater depths, as shown in Exhibit 8.5-5. The primary limitations of the air-lift sampler are the potential alteration of water quality parameters, the amount of air pressure that can be safely applied to the tubing, and the identification of a suitable source of compressed air.

## Exhibit 8.5-5
## AIR-LIFT SAMPLER


Discharge
Needle valve
Pressure gauge
Quick air hose coupler
Iron cap
Ground surface
Concrete
3/8" noncollapsing tubing
1¼" or 1½" plastic

The following are advantages of using the air-lift sampler:

- It can be used as a portable or permanently installed sampling system.
- It can be used both to flush the well and to sample.

Its disadvantages are as follows:

- It is not suitable for pH-sensitive parameters such as metals.
- It can damage the integrity of the filter pack around the well screen if the well is evacuated under high pressure and if the intake of the sample line is located within the screened interval.
- If air or oxygen is used, oxidation is a problem
- Gas stripping of volatile compounds may occur.

### 8.5.6.4.5 Nitrogen-Powered, Continuous-Delivery, Glass-Teflon Sampler

Sampling groundwater for trace organic pollutants requires a noncontaminating, nonadsorbing pump. Basing their work on an initial design by Stanford University, developers at Rice University created a groundwater sampling system that consists of a two-stage, all-glass pump connected by Teflon tubing and powered by nitrogen gas. The system (shown in Exhibit 8.5-6) contains four basic units: (1) a two-stage glass pump, (2) a solenoid valve and electronic timer, (3) a nitrogen tank and regulator, and (4) columns for removal of organics from the groundwater.

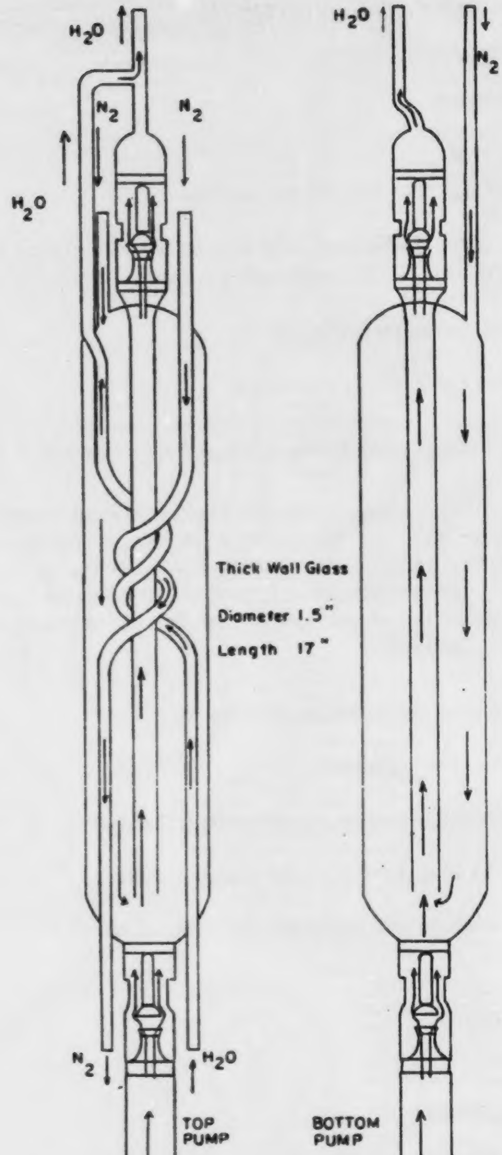
The following are advantages of using the glass-Teflon sampler:

- It is portable; AC power is not required
- It is constructed of noncontaminating, nonadsorbing materials.
- Variable flow rates up to 45 gallons per hour are obtainable.
- It can be used in well casings with minimum diameters of about 2 inches.

Its disadvantages are as follows:

- It requires high-purity nitrogen gas.
- Glass construction is somewhat more fragile than other materials.
- Stripping of $CO_2$ from water may be a problem for pH-sensitive parameters.
- Gas stripping of volatile compounds may occur.
- Generally low pumping rates are experienced.

## Exhibit 8.5-6
## NITROGEN-POWERED, GLASS-TEFLON PUMP


$H_2O$
$N_2$
$N_2$
$H_2O$
$H_2O$
$N_2$
Thick Wall Glass
Diameter 1.5"
Length 17"
$N_2$
$H_2O$
TOP PUMP
BOTTOM PUMP
Influent
Water

### 8.5.6.4.6 Gas-Operated Squeeze or Bladder Pump

These systems consist of a collapsible membrane inside a long, rigid housing; a compressed gas supply; tubing; and appropriate control valves. When the pump is submerged, water enters the collapsible membrane through the bottom check valve. After the membrane has filled, gas pressure is applied to the annular space between the rigid housing and the membrane, forcing the water upward through a sampling tube. When the pressure is released, the top check valve prevents the sample from flowing back down the discharge line, and water from the well again enters the pump through the bottom check valve. A diagram of the basic unit is shown in Exhibit 8.5-7.

The following are advantages of using the gas-operated squeeze or bladder pump:

- A wide range in pumping rates is possible
- A variety of materials can be used, depending on the parameters of interest.
- The driving gas does not contact the water sample, eliminating possible contamination or gas stripping.
- The pump can be constructed in diameters as small as 1 inch, permitting the use of small, economical monitoring wells.
- The pump is highly portable.

Disadvantages of the system are as follows:

- Large gas volumes and long cycles are necessary for deep operation. Pumping rates cannot match rates of submersible, suction, or jet pumps.
- Commercial units are relatively expensive (approximately $1,000 for currently available units).
- Use of the pump requires careful selection of bladder and tubing material, some of which is expensive.

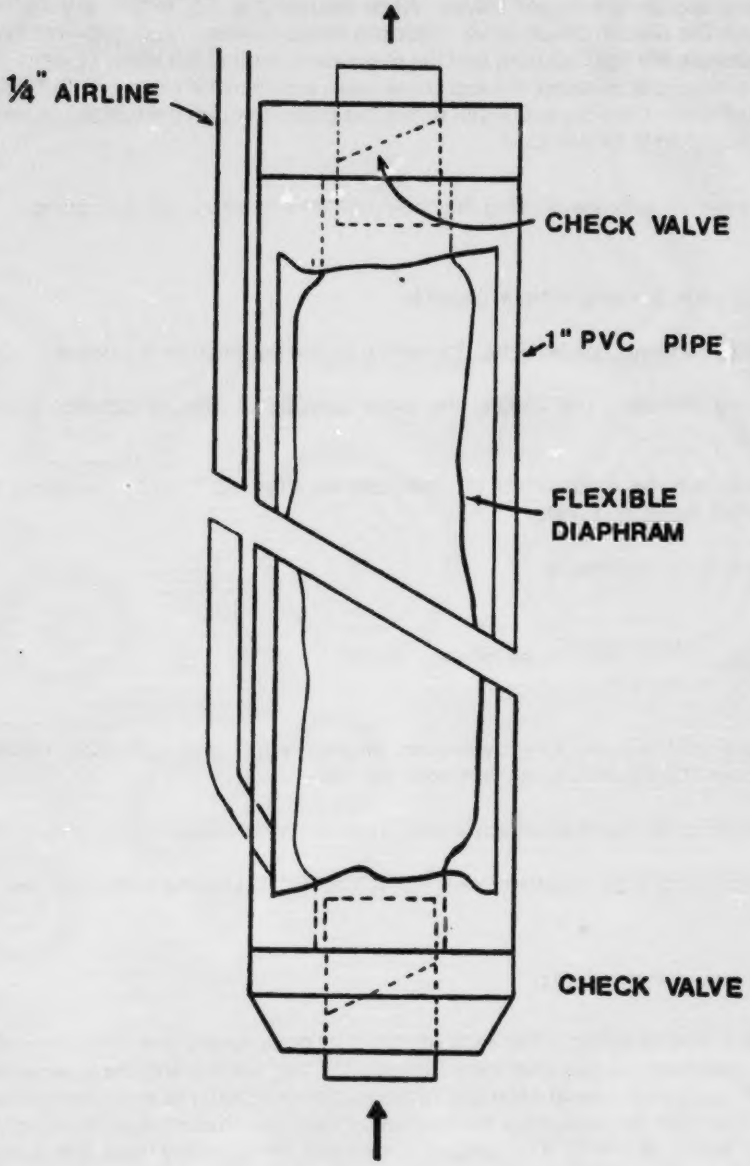
### 8.5.6.4.7 Gas-Driven Piston Pump

This pump is a double-acting piston type operated by compressed gas (Exhibit 8.5-8). The driving gas enters and exhausts from the gas chambers between the two pistons and the intermediate connector that joins them. Built-in check valves at each end of the pump allow water to enter the cylinders on the suction stroke and to be expelled to the surface on the pressure stroke. Current designs are constructed basically of stainless steel, brass, and PVC. Pumping rates vary with the pumping head, but pumping rates of 2.5 to 8 gallons per hour have been noted at 100 feet of pumping head.

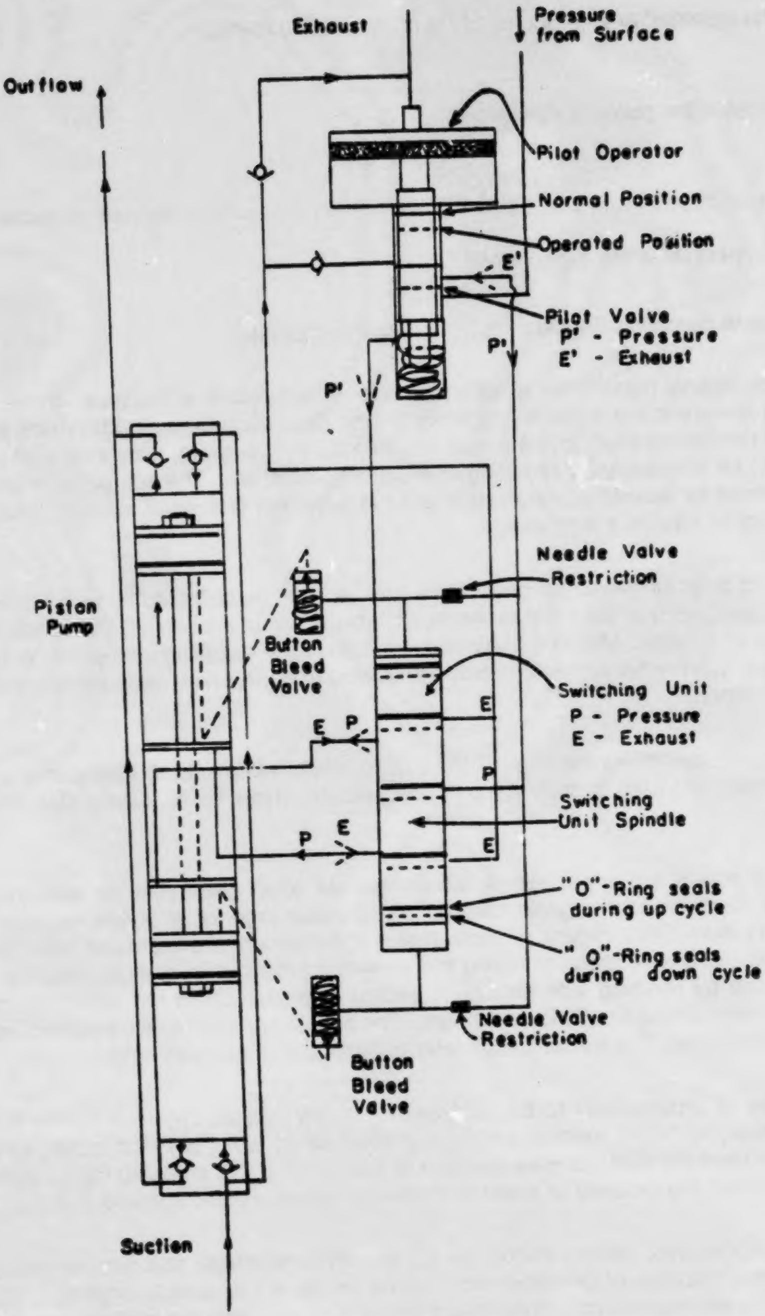
The following are advantages of using the gas-driven piston pumps:

- It isolates the sample from the operating gas.
- It requires no electrical power source.

## Exhibit 8.5-7
## GAS-OPERATED SQUEEZE PUMP


¼" AIRLINE
CHECK VALVE
1" PVC PIPE
FLEXIBLE
DIAPHRAM
CHECK VALVE

## Exhibit 8.5-8
## GAS-DRIVEN PISTON PUMP


Exhaust
Pressure from Surface
Outflow
Pilot Operator
Normal Position
Operated Position
E'
Pilot Valve
P' - Pressure
E' - Exhaust
P'
P'
Piston Pump
Needle Valve Restriction
Button Bleed Valve
Switching Unit
P - Pressure
E - Exhaust
E
E
P
P
Switching Unit Spindle
P
E
E
"O"-Ring seals during up cycle
"O"-Ring seals during down cycle
Needle Valve Restriction
Button Bleed Valve
Suction

- It operates continuously and reliably over extended periods of time.
- It uses compressed gas economically.
- It can be operated at pumping heads in excess of 500 meters.

Disadvantages of the pump are as follows:

- Particulate material may damage or inactivate the pump unless the suction line is filtered.
- Low pumping rates are experienced.

### 8.5.6.4.8 Special Sampling Considerations for Organic Samples

Sampling for organic parameters is not a standardized procedure at this time. Some of the equipment and methods in use are in the research stage. However, the concepts are fundamental, and any particular item or method can be modified to suit actual field needs. Furthermore, expensive and sophisticated procedures may not be necessary for sampling or monitoring all areas. The points that must be kept in mind include the potential for sample contamination and the extremely fine detail, subject to expert rebuttal, that may be necessary to support a legal action.

Grab samples of groundwater for nonvolatile analysis may be collected by using the system shown in Exhibit 8.5-9. This system is used where the water table is within suction lift; the sampled water contacts only sterile glass and Teflon. More sophisticated versions of the sampling configuration are available commercially. The sampled water is then carefully transferred to appropriate glass sample containers for shipment to the laboratory.

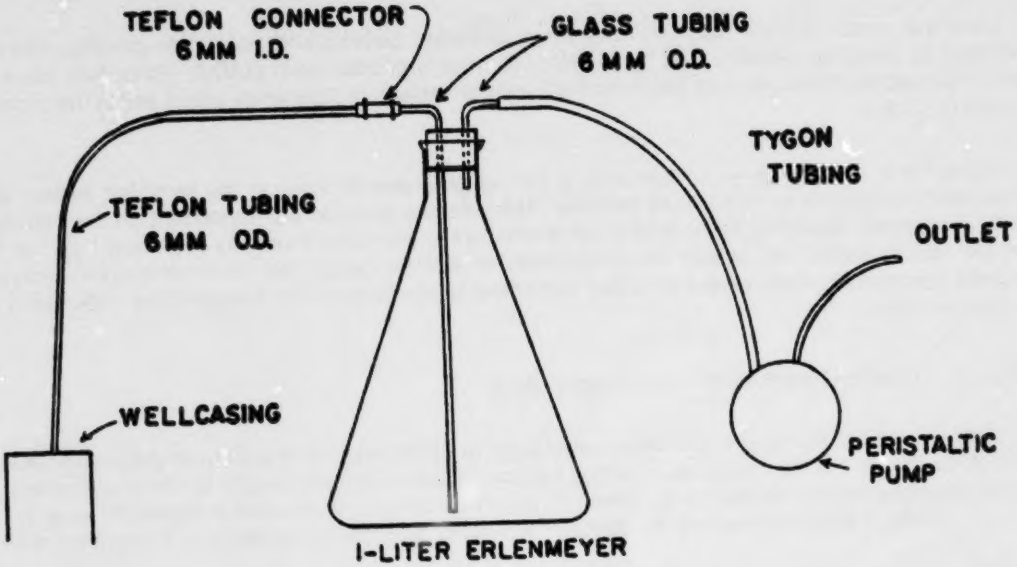
For sampling at depths beyond suction lift, a noncontaminating submersible pump should be used to pump the groundwater to the surface through scrupulously clean Teflon tubing directly into appropriate sample containers.

The most commonly employed sample containers are 40-ml glass vials for analyses requiring small sample volumes, such as total organic carbon, and 1-gallon jugs for analyses requiring relatively large volumes, such as extractable organics. Both types of containers are equipped with Teflon-lined screw caps. Like all glassware used in the sampling and analytical procedures, sample containers are thoroughly cleaned before use by washing with detergent, rinsing extensively with tap water, rinsing in high-purity deionized water, and heating to 105°C for 2 hours. The bottles are most easily obtained from the EPA CLP Sample Bottle Repository. The reader should refer to Section 6 of this compendium.

Grab samples of groundwater to be analyzed for highly volatile organics by the Bellar-Lichtenberg volatile organic analysis (VOA) method are usually obtained by using a Teflon bailer, as noted in Exhibit 8.5-4. Bailers are used for VOA samples because of the possibility of stripping highly volatile constituents from the sample under the reduced or elevated pressure occurring in the systems that use pumps.

Continuous procedures, using selected adsorbents to concentrate and recover organic constituents from relatively large volumes of groundwater, may be employed to sample organic pollutants when the analytical sensitivity and sample uniformity attainable by grab sampling are inadequate. These procedures are applicable for most organic pollutants except those of very high volatility.

## Exhibit 8.5-9
## SYSTEM FOR GRAB SAMPLING


TEFLON CONNECTOR
6MM I.D.
GLASS TUBING
6MM O.D.
TYGON
TUBING
TEFLON TUBING
6MM O.D.
OUTLET
WELLCASING
PERISTALTIC
PUMP
1-LITER ERLENMEYER

A special sampling system is shown in Exhibit 8.5-10. In this illustration, water is pumped directly from the well through Teflon tubing (6 mm outside diameter (OD)) to two glass columns of adsorbent in series. A peristaltic pump is located on the outlet side of the columns for sampling with suction lift. A noncontaminating submersible pump may be used at greater depths and may be superior for practically all sampling uses.

All components of the system that contact the water sample before emergence from the second column are, with the exception of the adsorbent, glass or Teflon. Exhibit 8.5-11 shows a typical sampling system installed in specially constructed housing to form self-contained sampling units that are easily transported and set up in the field.

Columns prepared from macroreticular resin, activated carbon, and polyamide particles have been employed in sampling systems. Of these materials, macroreticular resin (XAD-2, Rohm and Haas Company, Philadelphia, Pennsylvania) has been the most convenient and generally useful and is the current adsorbent of choice.

Sampling is conducted by continuously pumping groundwater through the sampling system at flow rates usually ranging from 10 to 30 ml per min. The volumes sampled are dependent on the desired sensitivity of analysis. Sampling 50 liters of water is sufficient to provide a sensitivity of at least 1 μg per liter (1 part per billion (ppb)) for almost all compounds of interest using gas chromatographic techniques. Volumes sampled are determined by using calibrated waste receivers to measure the water leaving the sampling systems.

### 8.5.6.4.9 Volatile Organics in the Unsaturated Zone

Water should be sampled in the unsaturated zone to detect and follow pollutants migrating toward the water table. Highly volatile compounds, which include the low-molecular- weight chlorinated hydrocarbons such as trichlorethylene, are difficult to detect. These compounds are released in significant quantities into the environment, exhibit carcinogenicity, and are implicated in numerous cases of groundwater pollution.

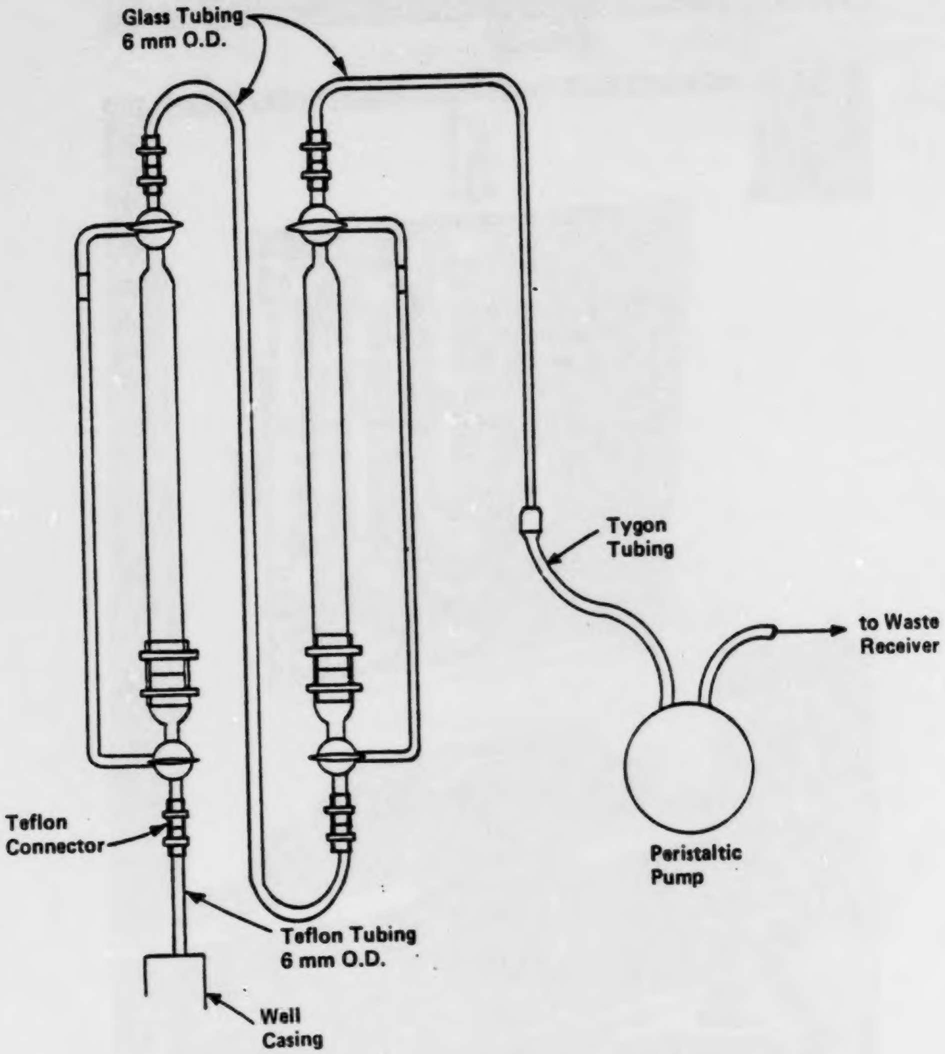
Soil-water samples may be collected using the device depicted in Exhibit 8.5-12, which consists of a sampler, a purging apparatus, and a trap connected to sources of nitrogen gas and a vacuum. The soil-solution sampler consists of a 7/8-inch OD (2.2-cm) porous ceramic cup, a length of 3/4-inch OD Teflon or PVC pipe, and a Teflon stopper fitted with 3-mm OD Teflon exhaust and collection tubes. The length of the pipe is dictated by the depth of sampling desired, which is limited to a maximum of about 20 feet. The device is basically a suction lysimeter with the attendant limitations. The purging apparatus and trap are parts of the Tekmar LSC-1 liquid-sample concentrator to which have been added Teflon valves and "Tape-Tite" connectors. The purging apparatus is borosilicate glass, while the trap consists of Tenax-GC porous polymer (60/80 mesh), packed in a 2-mm x 28-cm stainless steel tube plugged with silane-treated glass wool. The purge gas is ultrahigh purity, oxygen-free nitrogen. The vacuum is provided by a peristaltic pump.

Before the sample is collected, the purging apparatus is cleaned with acetone and distilled water and then baked at 105°C to 108°C for at least an hour. In the field, the device is rinsed thoroughly with distilled or organic-free water between samples, and special care is taken to force the rinse water through the glass frit.

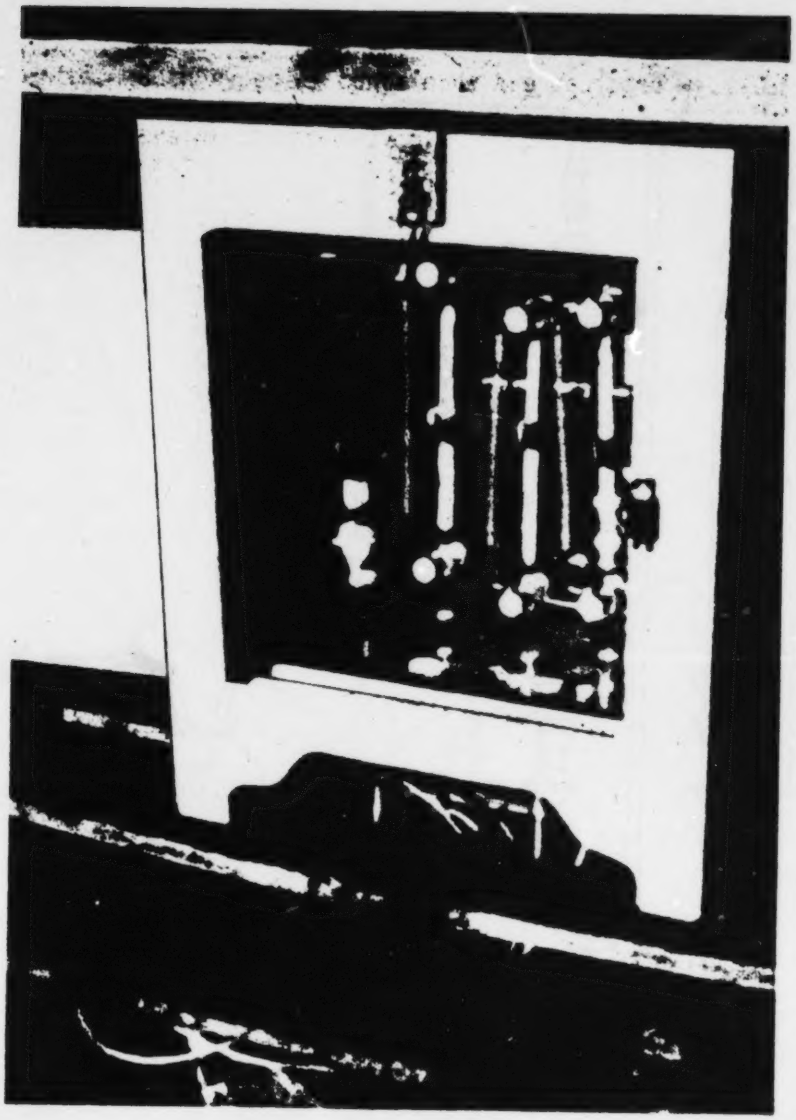
The soil-solution sampler is driven to the bottom of a pre-augered 19-mm (0.75-inch) diameter hole. This procedure is done very carefully to ensure intimate contact between the ceramic cup and the soil.

Before collecting a sample, the exhaust tube is opened to the atmosphere, and the collection tube is disconnected and pumped to remove any solution that may have leaked into the tube through the porous

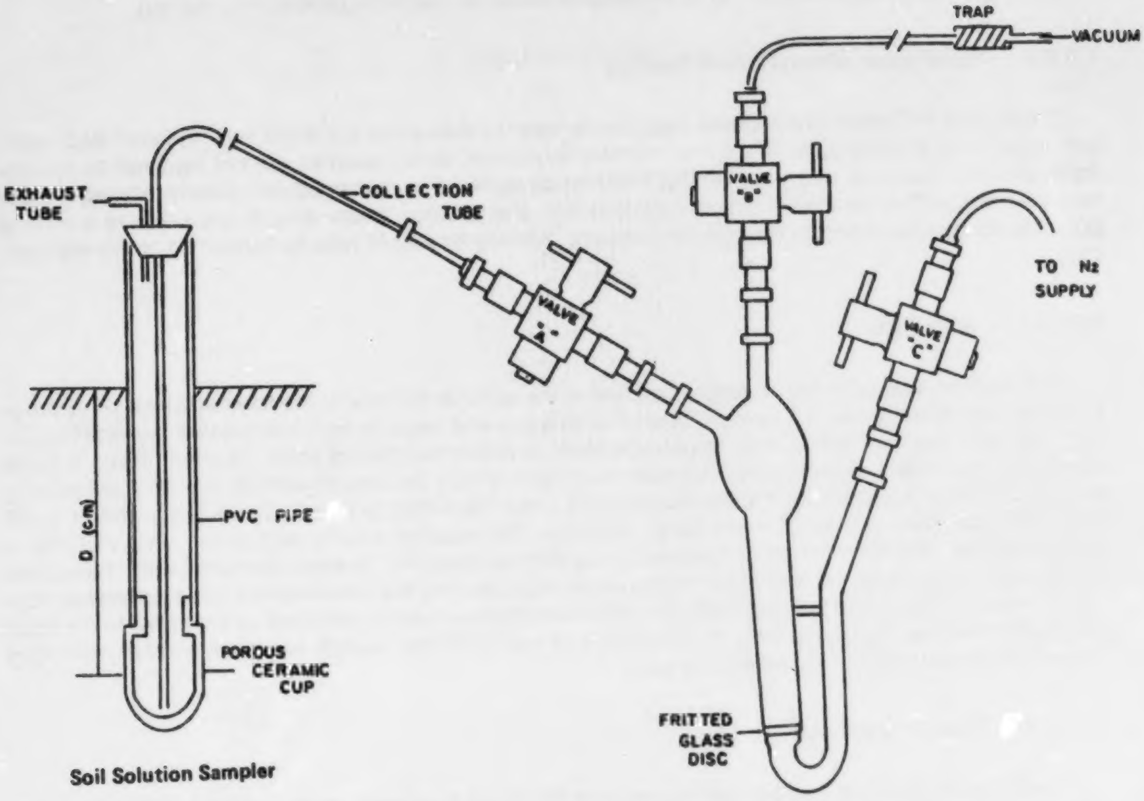
## Exhibit 8.5-10
## CONTINUOUS SAMPLING SYSTEM FOR ORGANICS


Glass Tubing
6 mm O.D.
Tygon
Tubing
to Waste
Receiver
Peristaltic
Pump
Teflon
Connector
Teflon Tubing
6 mm O.D.
Well
Casing

## Exhibit 8.5-11
## SELF-CONTAINED SAMPLING UNIT FOR ORGANICS



## Exhibit 8.5-12
## SOIL-WATER SAMPLING DEVICE FOR VOLATILE ORGANICS


TRAP
VACUUM
EXHAUST TUBE
COLLECTION TUBE
VALVE "B"
VALVE "A"
VALVE "C"
TO N₂ SUPPLY
PVC PIPE
D (cm)
POROUS CERAMIC CUP
FRITTED GLASS DISC

Soil Solution Sampler

Purging Apparatus

cup. Then the collection tube is reconnected to the purging apparatus, the exhaust tube is closed with a pinch clamp, and 5 to 10 ml of solution is collected by closing valve C and opening valves A and B (see Exhibit 8.5-12). After sample collection, the exhaust tube is opened to remove from the sampler and collect on the trap any of the compounds that may have volatilized in the sampler. Following this procedure, valve A is closed and valve C is opened. Nitrogen gas is then bubbled through the solution at a rate of 40 ml per minute for 10 minutes to purge volatile organics from the solution. Traps are capped and returned to the laboratory for analysis within 6 hours of collection or for storage at 20°C for later analysis. Chemical concentrations are determined according to procedures based on the Bellar-Lichtenberg method.

### 8.5.6.5 Water-Level Measurement Devices

Water-level indicators are portable instruments used to determine the water level in boreholes, wells, and other open underground structures. Generally, outside power sources are not required to operate these devices. However, many require that batteries be replaced or recharged periodically. Measurements may be made with a number of different devices and procedures. Measurements are taken to a scribed point placed by a surveyor on the inner well casing. The reader should refer to Section 14 of this compendium.

#### 8.5.6.5.1 Steel Tape

The chalked steel tape with a weight attached to the lower end is one of the most accurate procedures for measuring water levels. The weight keeps the tape taut and helps lower it into the well (see Exhibit 8.5-13). The tape can be chalked with carpenter's chalk, ordinary blackboard chalk, or other chalk. The line where the color changes on the tape indicates the length of tape that was immersed in water. Subtracting this length from the reading at the measuring point gives the depth to water. Cascading water in a well may mask the mark of the true water level. However, this situation usually occurs only in a well that is being pumped. Another method of measuring may then be required. In small-diameter wells, the volume of the weight may cause the water level to rise in the pipe, causing the measurement to be somewhat inaccurate. Another problem associated with the steel tape measurement is that chalk or impurities in the chalk may contaminate a monitoring well. If the integrity of a groundwater sample is critical, another method of measuring the water level may have to be used.

#### 8.5.6.5.2 Electric Sounders

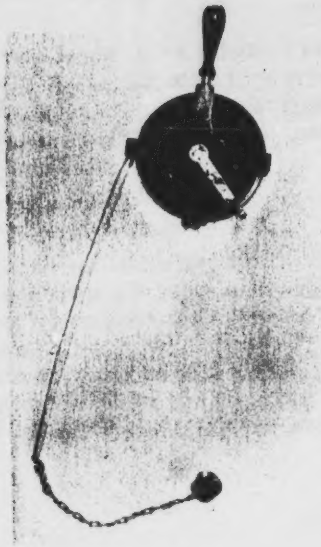
Electric sounders may also be used to measure the depth to water in wells (Exhibit 8.5-13). There are a number of commercial models available, none of which is entirely reliable. Many sounders use brass or other metal indicators clamped around a conductor wire at 5-foot intervals to indicate the depth to water when the meter indicates contact. The spacing of these indicators should be checked periodically with a surveyor's tape to assure accurate and reliable readings.

Some electric sounders use a single-wire line and probe, and rely on grounding to the casing to complete the circuit; others use a two-wire line and double contacts on the electrode. Most sounders are powered with flashlight batteries, and the closing of the circuit by immersion in water is registered on a milliammeter. Experience has shown that two-wire circuits with a battery are by far the most satisfactory electric sounders.

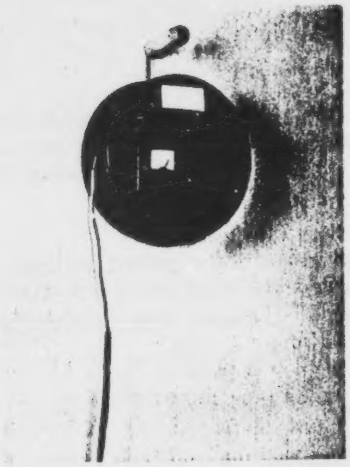
Electric sounders are generally more suitable than other devices for measuring the depth to water in wells that are being pumped because they generally do not require removal from the well for each reading. However, when there is oil on the water, water cascading into the well, or a turbulent water surface in the well, measuring with an electric sounder may be difficult. Oil not only insulates the contacts of the probe, but it will also give an erroneous read ing if there is a considerable thickness of oil.

## Exhibit 8.5-13
## WATER-LEVEL MEASUREMENT DEVICES

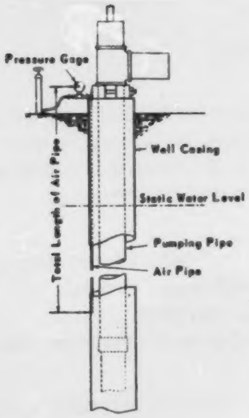
Chalked Steel Tape



Popper



Electric Sounder


Pressure Gage
Well Casing
Static Water Level
Pumping Pipe
Air Pipe
Total Length of Air Pipe

Air Line

In some instances, it may be necessary to insert a small pipe in the well between the column pipe and the casing from the ground surface to about 2 feet above the top of the pump bowls. This pipe should be plugged at the bottom with a cork or similar seal that is blown out after the pipe is set. Measurements with the electric sounder can then be made in the smaller pipe where the disturbances are eliminated or dampened, the true water level is measured, and the insulating oil is absent. When oil is present, it is necessary to determine the thickness and density of the oil layer before calculating the true water level.

Exhibit 8.5-14 illustrates a convenient arrangement for direct measurement of drawdown during pumping tests. A marker on the sounder wire is referred to a value on the tape, and the same marker is used as a reference to determine drawdown through changes on the tape when contact with the water is made. A new marker is used each time the water level drops by an increment of 5 feet.

### 8.5.6.5.3 Poppers

A simple and reliable method for measuring the depth to water in observation holes between 1-1/2 and 6 inches in diameter is the use of a steel tape with a popper (see Exhibit 8.5-13). The popper is a metal cylinder that is 1 to 1-1/2 inches in diameter and 2 to 3 inches long with a concave undersurface; the popper is fastened to the end of a steel tape. When the popper is raised a few inches and dropped to hit the water surface, it makes a distinct "pop." Adjusting the length of tape determines the point at which the popper just hits the surface. Poppers are generally not satisfactory for measuring pumping wells because of the operating noise and lack of clearance, and they are not effective if the water surface is opposite the well screen.

### 8.5.6.5.4 Floats

Float devices are similar to poppers for measuring depth to water. The popper is replaced with a small float, and the depth to water is determined by the slack created by the tape when the float hits the surface of the water.

### 8.5.6.5.5 Air Lines

Permanent pump installations should always be equipped with an access hole for probe insertion or for an air line and gauge, or preferably both, to measure drawdown during pumping. An air line is accurate only to about 0.5 foot unless it is calibrated against a tape for various drawdowns, but it is sufficiently accurate for checking well performance.

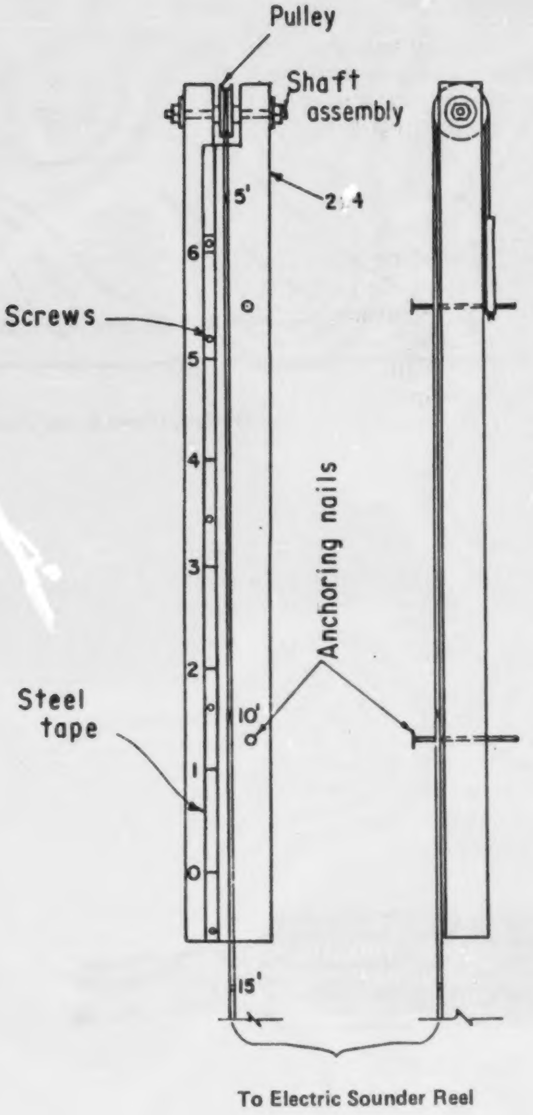
Artesian wells with piezometric heads above the surface of the ground are conveniently measured by capping the well with a cap that has been drilled, tapped, and fitted with a plug that is removed for the insertion of a Bordon gauge or mercury manometer stem. The static level is determined from the gauge or manometer reading after the pressure has stabilized.

For continuous records, a recording pressure gauge may be used.

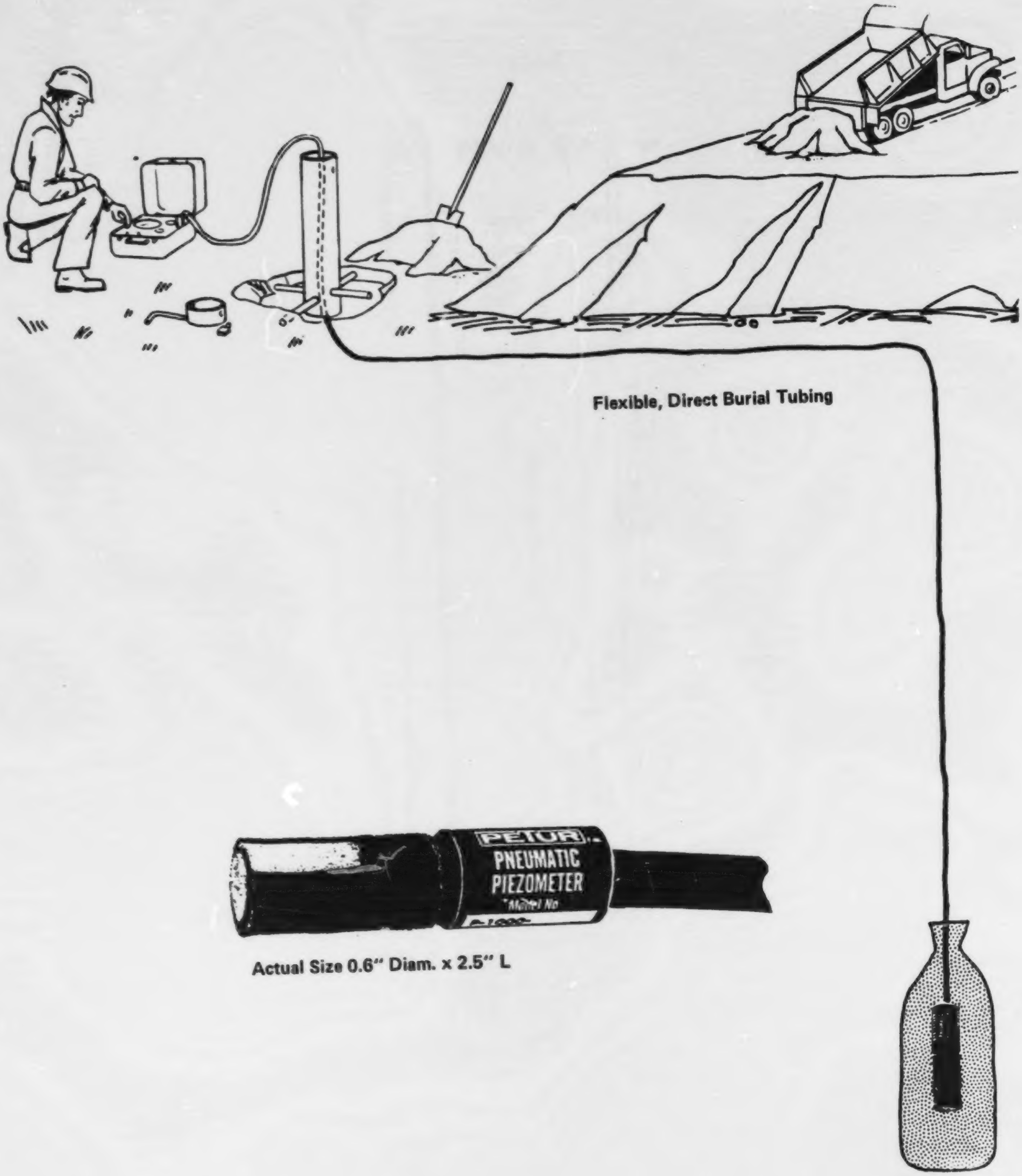
### 8.5.6.5.6 Pneumatic Piezometers

Pneumatic piezometers are used to measure pore pressures or pore pressure changes within boreholes or embankments (see Exhibit 8.5-15). Pneumatic piezometers are usually connected to the surface with flexible tubing. To operate a pneumatic piezometer, a portable readout unit is usually required (see Exhibit 8.5-16). The readout unit contains an internal pressure tank and data gauge. The pneumatic piezometer measures hydrostatic pressure in a manner similar to that of a simple air line.

## Exhibit 8.5-14
## DIRECT DRAWDOWN MEASUREMENT BOARD


Pulley
Shaft assembly
5'
2x4
6
Screws
5
4
Anchoring nails
3
2
Steel tape
10'
1
0
15'
To Electric Sounder Reel

## Exhibit 8.5-15
## PNEUMATIC PIEZOMETER


6"
PETUR
PNEUMATIC
PIEZOMETER
Model No
P-1000

Flexible, Direct Burial Tubing

Actual Size 0.6" Diam. x 2.5" L

Exhibit 8.5-16

## PORTABLE PNEUMATIC PRESSURE READOUT UNIT

TANK PRESSURE
CHARGE
RECOVER
PIEZO INPUT
PIEZO BY-PASS
WATER SAMPLER
PETUR USA

The two primary advantages of using a pneumatic piezometer instead of a standpipe piezometer are that a pneumatic piezometer eliminates filter tip plugging and time lag. These two interdependent problems, inherent in all stand pipes, result from the large volumetric change and the time required for groundwater to permeate through the soil and fill the pipe to the piezometric head. In low-permeability soils, the time lag can become so long that it is impossible to obtain meaningful pore pressure data with a standpipe. Instrument time lag is completely eliminated when pneumatic piezometers are used. Since the time lag problem is eliminated, pneumatic piezometers are very useful for monitoring fast water level changes that occur during pump tests or other hydraulic conductivity tests. Since this procedure may be model-specific, the manufacturer's recommendations for the equipment to be used should be called out in the QAPjP.

#### 8.5.6.5.7 Continuous Water Level Recorders

There are a large number of different models of continuous water level recorders. Typically, these recorders use floats, electric sounders, pneumatics, or other devices previously described. A float-balance continuous recorder is shown in Exhibit 8.5-17.

#### 8.5.6.5.8 Sonic Water Level Measurement

Under proper conditions, depth to water in a well can be measured by a sonic device. This device uses a compressed air charge or fires a blank shell to generate a sonic wave down the well. The round-trip wave travel time is measured, and the depth to water is calculated. Care must be taken in reading the wave charts because discontinuities in the casing or in other well construction components may generate anomalous wave forms and may cause inaccurate determinations of water level depth.

### 8.5.6.6 Field Parameter Measurements

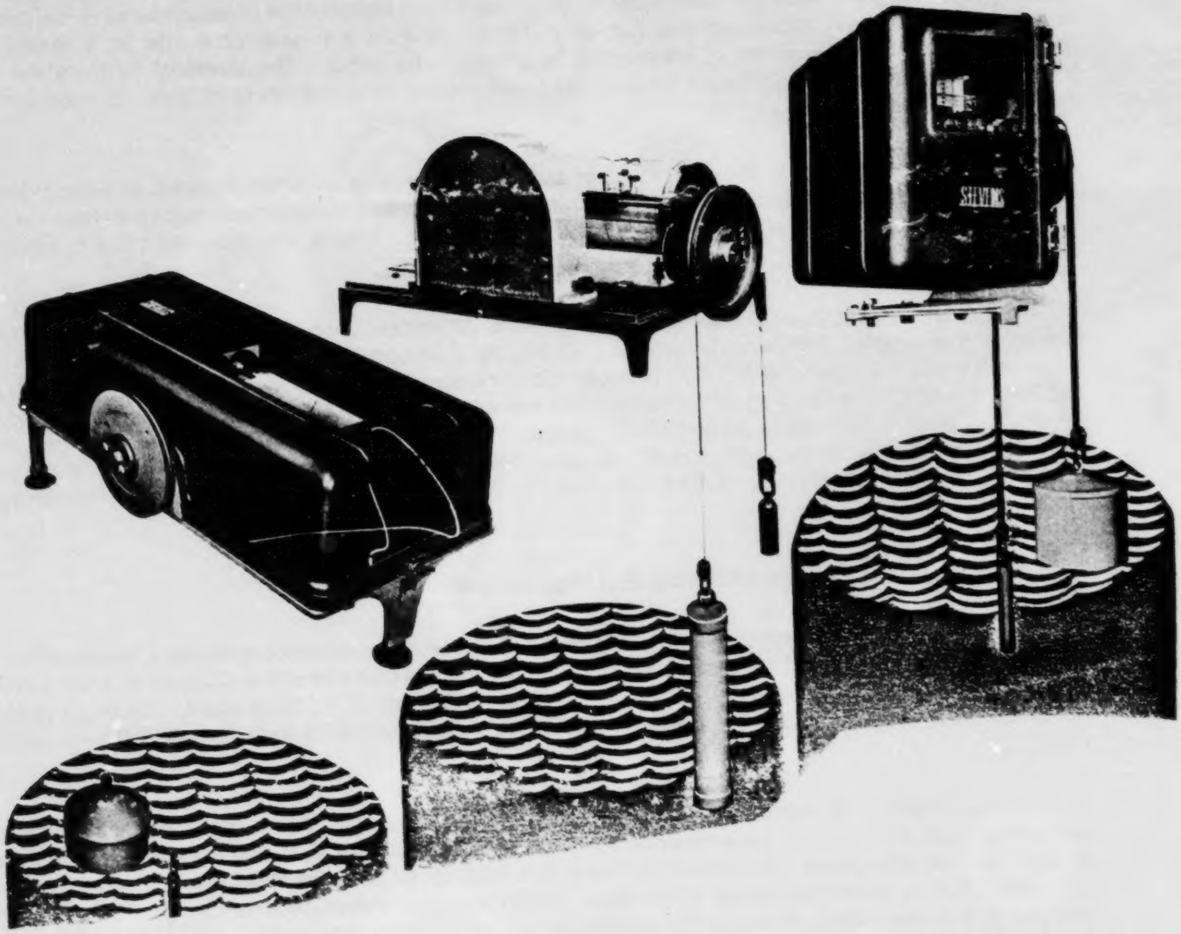
#### 8.5.6.6.1 Measurement and Interpretation of pH

The pH of natural water is ordinarily determined by measuring the potential between a glass electrode and a reference electrode immersed in the solution. The potential must be measured with a sensitive electrometer or similar device that does not permit a significant flow of current. The design of pH meters has been greatly improved in recent years, and equipment now available measures pH to the nearest 0.01 pH unit with excellent stability and consistency either in the field or laboratory. Because the pH is a logarithm, measurements to two decimal places may still be imprecise as compared to the usual measurements of concentrations of the other solute species.

The equilibria in a groundwater system are altered when the water is taken into a well and pumped to the surface. A pH measurement taken at the moment of sampling may represent the original equilibrium conditions in the aquifer satisfactorily; however, if the water is put into a sample bottle and the pH is not determined until the sample is taken out for analysis (days, weeks, or months later), the measured pH may have no relation to the original conditions. Besides gaining or losing carbon dioxide, the solution may be influenced by reactions such as oxidation of ferrous iron, and the laboratory pH can be a full unit different from the value at the time of sampling. A laboratory determination of pH can be considered as applicable only to the solution in the sample bottle at the time the determination is made. Accurate measurement of pH in the field should be standard practice for all groundwater samples.

Typical procedures for calibrating the instrument and for obtaining the pH vary with manufacturer and model. Equipment should be recalibrated at each sample location and when ambient temperature changes significantly. Equipment manuals provide guidance for calibration.

**Exhibit 8.5-17**
**CONTINUOUS WATER-LEVEL INDICATORS**



### 8.5.6.6.2 Specific Electrical Conductance

Electrical conductance, or conductivity, is the ability of a substance to conduct an electric current. The American Society for Testing and Materials (ASTM) has defined electrical conductivity of water as "the reciprocal of the resistance in ohms measured between the opposite faces of a centimeter cube of aqueous solution at a specified temperature." This definition further specifies that units for reporting conductivity shall be "micromhos per centimeter at temperature °C." Geophysical measurements of resistivity, however, are commonly expressed in ohmmeters, referring to a cube 1 meter on a side, so it should be emphasized that conductances of water refer to a centimeter cube. The standard temperature for laboratory measurements is 25°C, but some values taken at other temperatures exist; thus it is important to specify the temperature.

Because conductance is the reciprocal of resistance, the units in which specific conductance is reported are reciprocal ohms, or mhos. Natural waters have specific conductances much less than 1 mho; to avoid inconvenient decimals, data are reported in micromhos. That is, the observed value in mhos is multiplied by $10^6$.

The specific conductance of a groundwater sample is dependent upon the total dissolved solids (TDS) content of the sample. Typically, the ratio of TDS (mg per l) to specific conductance (mmhos per cm) is between 0.6 and 0.8. Because the TDS concentration and specific conductance of a sample may be pH-dependent, measurements of specific conductance should occur in the field along with the measure ment of pH. Accuracy in both measurements is important. Before the start of sampling for chemical analysis, the measurements for temperature, specific conductance, and pH should be stable over two or three well volumes. Equipment manuals should be referenced for proper calibration and operation of all field analytical equipment.

### 8.5.6.6.3 Oxidation-Reduction Potential (Eh) Measurement

The ability of a natural environment to bring about an oxidation or reduction process is measured by a quantity called its redox potential and is designated as Eh. Eh is a measure of the ability of an environment to supply electrons to an oxidizing agent or to take up electrons from a reducing agent. The redox potential system is a measure of the cumulative redox potential of a number of individual oxidation-reduction reactions.

The measurement of redox potential is not simple or unambiguous. Some reactions that determine redox potentials are slow, so instantaneous readings with the platinum electrode do not give true equilibrium potential differences. This slowness means that most redox potential measurements in nature give only qualitative or semi-quantitative information. When accurate determinations of redox potential are necessary, it is desirable to measure the concentrations of redox couples, such as $SO^{-2}_4/H_2S$, $CO_2/CH_4$, $Fe^{+3}/Fe^{+2}$, $NO_3^-/N_2$, and so forth.

Qualitative measure of Eh is conducted using a noble metal (usually platinum) and a reference electrode system or a combination electrode using a specific-ion meter that will measure in millivolt units. Reference solutions with known Eh are used to obtain the potential and to check the accuracy of the electrode system.

If Eh is to be measured, it should be measured in the field using the following procedures:

- Prepare and calibrate equipment according to manufacturer's specifications.
- Bring the reference ZoBell solution to sample temperature and record temperature.

- Measure potential, in millivolts, of the ZoBell solution at sample temperature ($Eh_{ZoBell(obs)}$) and check against theoretical value at measured temperature (should be ±10 millivolts) ($Eh_{ZoBell+Ref}$).

- Place electrode in Eh cell and allow readings to stabilize (20 minutes plus).

- Turn off water flow to prevent streaming potential and immediately take reading.

- Record data ($Eh_{obs}$) and calculate Eh relative to standard hydrogen electrode.

Calculate system Eh as follows:

$$Eh_{sys} = Eh_{obs} + Eh_{ZoBell+Ref} - E_{ZoBell(obs)}$$

Report Eh to the nearest ±10 millivolts. It should be noted that oil and grease in the sampled solution may coat the noble-metal electrode and provide erroneous readings.

### 8.5.6.7 Filtration

The need and desirability of filtering samples is dictated by the objectives of the study and sampling as specified in the investigation sampling plan. If the objective is to assess migration mechanisms in conjunction with migration pathways, then it is necessary to know the concentration of dissolved versus total constituents. This comparison permits an assessment of mobility in a true dissolved state as opposed to a particulate or colloidal state. The assessment of the former requires the analysis of filtered samples; the latter requires analysis of both filtered (for dissolved) and unfiltered (for total) samples. The difference permits a determination of suspended contribution.

Filtering is necessary to analyse samples for inorganic constituents, many of which are acidified before or during analysis. This acidification may release ions held on particles and change the constituent chemistry of the solution.

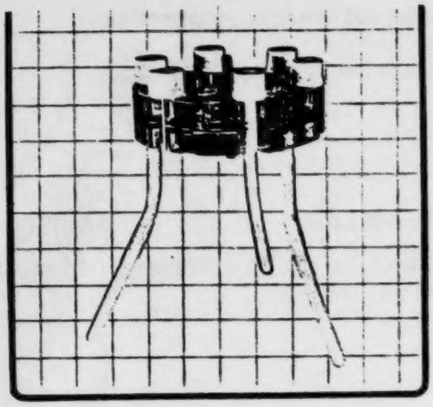
The removal of suspended solids may be accomplished through several techniques. Filtration through a 0.45-micron micropore membrane filter is the most common field method used to remove suspended solids. This filter permits a reasonable and practical distinction between true solute material and material that may be considered particulate or not in true solution. For extremely turbid samples, large particulates can be removed with a coarse filter before the 0.45-micron filter is used. Large-capacity 0.45 micron filters exist but are expensive when a large number of turbid samples must be collected.

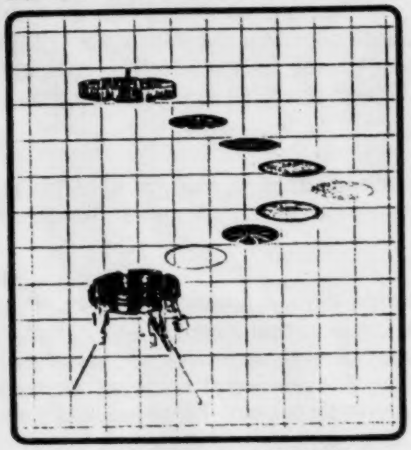
Pressure and suction filtering devices are commonly used in the field. A typical filter holder is shown in Exhib it 8.5-18. Small peristaltic pumps are commonly used with this type of filtering device (see Exhibit 8.5-18). Inert gas pressure-filter devices are preferred to suction or compressed air pumps. Hand pump filtering apparatuses have been used.

### 8.5.6.8 Materials for Well Construction

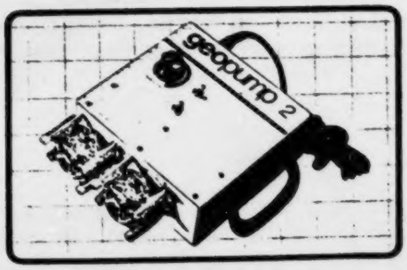
The selection of materials for well construction and sample collection, handling, and storage is a critical consideration in planning the monitoring program. The materials should retain their structural integrity for the duration of the monitoring program under subsurface conditions. The material should neither adsorb nor leach chemical constituents. The material combinations must also be compatible with each other and with the goals of the sampling effort. (The reader should refer to Exhibit 8.5-19 for a typical monitoring well installation.)

## Exhibit 8.5-18
## FILTERS AND PERISTALTIC PUMP



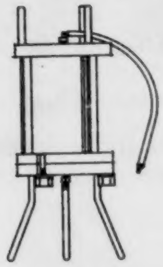


**BACKFLUSH FILTER HOLDER**
**Parts Break Down**

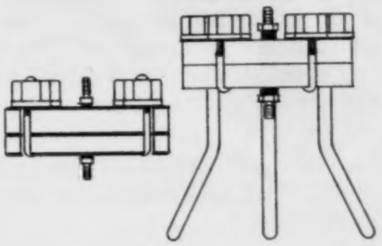


**PERISTALTIC PUMPS**
**Electric or Hand Powered**

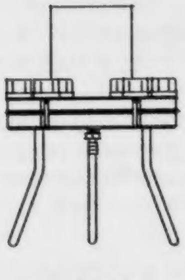
GEOTECH MEMBRANE
FILTER HOLDERS



PRESSURE



BACKFLUSHING



VACUUM

### 8.5.6.8.1 Overview of Subsurface Conditions

Most common piping materials (steel, polyvinyl chloride, and iron) meet the structural requirements needed for well casings to withstand normal subsurface pressures for depths of up to approximately 30 meters (90 feet). In deeper monitoring situations, the use of corrosion-resistant metallic casing for large-diameter (greater than 10 centimeters or 4 inches) may be required to provide necessary structural integrity. The practices of local water well construction and regional EPA requirements should serve as a guide.

Metallic corrosion problems may be encountered under either oxidizing or reducing conditions and are aggravated by high dissolved-solids content. Other materials (thermoplastics) may deteriorate under the influence of dissolved chemical substances or direct contact with wastes. Whether the well construction retains its integrity or not, there are also potential problems because of microbial attachment and growth and the sorptive capacity of the exposed materials for the chemical species of interest. Representative sampling depends on the choice of materials that can retain their integrity over the entire length of a well casing, from the aerobic, unsaturated surface zone to the unusual conditions in the saturated zone.

### 8.5.6.8.2 Chemical Properties of Water and Their Effects on Various Materials

A groundwater monitoring network is designed and constructed with the casing and materials that are compatible with the subsurface environment. The materials should be compatible with probable mixtures of groundwater and chemical substances from the contaminant source. Compatibility must be judged from a structural and chemical standpoint. Structural considerations are treated in detail in the 1980 National Water Well Association publication, *Manual on the Selection and Installation of Thermoplastic Water Well Casing*. The main criterion for chemical compatibility should be that the long-term interaction of the casing or sampling materials with the groundwater will not cause an analytical bias in the interpretation of the chemical analysis of the water samples.

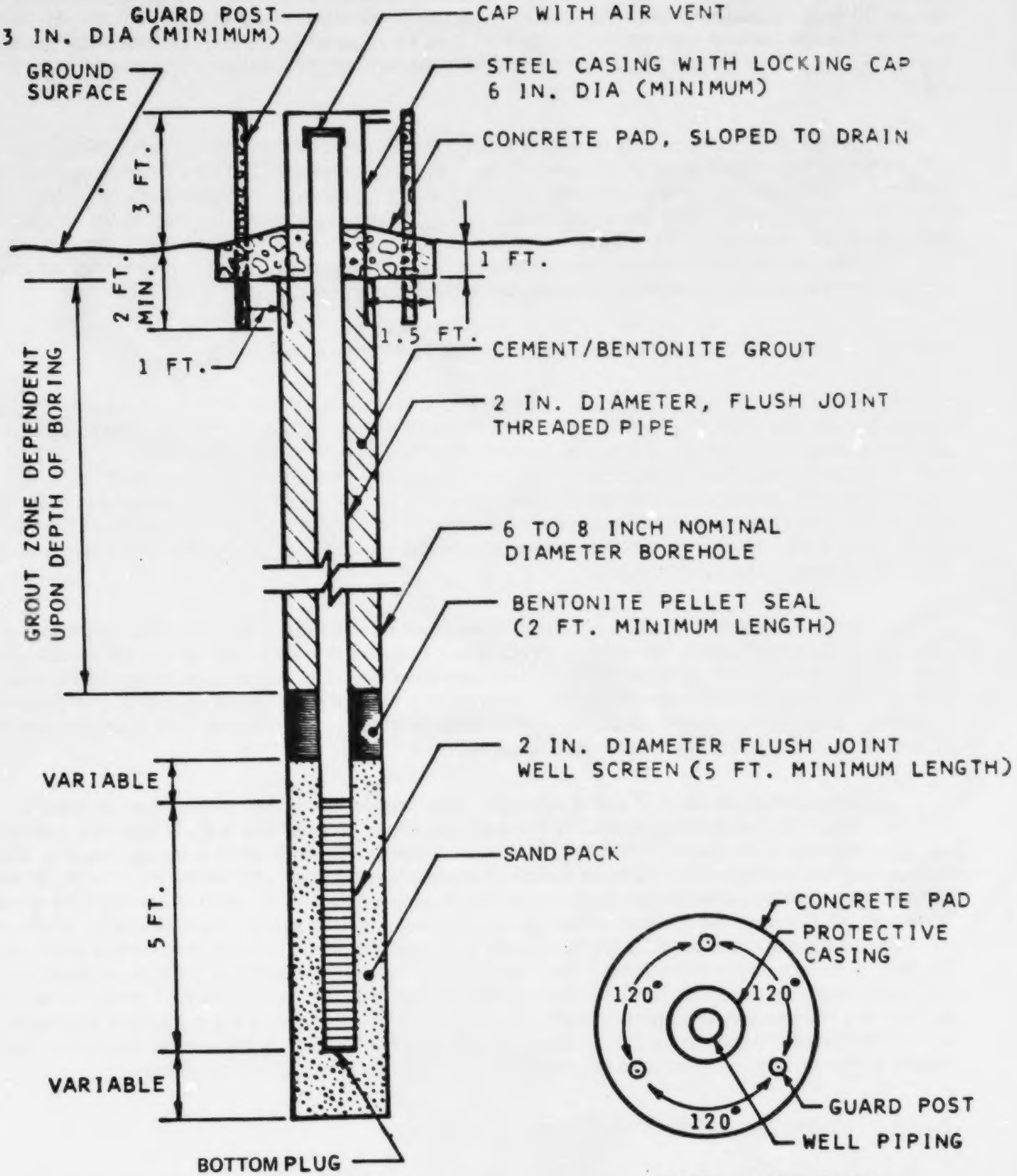
The study of the effects of water or aqueous solutions on materials (and vice versa) presents many obstacles to the investigator. For leaching effects alone, there are at least six critical system variables that must be controlled or considered, including chemical composition of the solution, temperature, rate of flow, and composition of the material (its age, pretreatment, and the surface area exposed). For purposes of material selection for ground water monitoring, static or flowing tests with solutions approximating the expected range of solution composition should be sufficient.

Well casing materials are rigid and nonporous. They present a very low surface area to water in the wellbore relative to that of the adjacent soil or aquifer particles. An extensive body of literature deals with sorptive interactions of dissolved chemical species in natural waters with solid surfaces. Most of these studies describe the adsorption of trace metals or organic compounds (adsorbates) on mineral particles (adsorbents). Surface area (or particle size) and the organic content of the solid phase are cited almost universally as important variables in the adsorption process. Mineral phases such as quartz, aluminum, hydrous metal oxides, and clays, as well as natural sediments, have been studied with surface areas ranging from 5 to more than 250 square meters per gram. These active surfaces have been observed to routinely absorb up to several hundred micro grams of adsorbate per square meter of surface area. The applicability of laboratory adsorption experiments to the condensed media of the subsurface is a matter of some controversy. However, a simple qualitative comparison of well casing versus subsurface solids should suffice to discount adsorptive interferences from materials selection considerations.

### 8.5.6.8.3 Teflon Well Casing

Teflon represents a nearly ideal well construction material. Inertness to chemical attack, poor sorptive properties, and low leach potential are clear advantages of rigid Teflon for well screens and casing.

## Exhibit 8.5-19
## TYPICAL MONITORING WELL INSTALLATION


GUARD POST
3 IN. DIA (MINIMUM)
CAP WITH AIR VENT
STEEL CASING WITH LOCKING CAP
6 IN. DIA (MINIMUM)
GROUND SURFACE
CONCRETE PAD, SLOPED TO DRAIN
3 FT.
1 FT.
2 FT. MIN.
1.5 FT.
1 FT.
CEMENT/BENTONITE GROUT
2 IN. DIAMETER, FLUSH JOINT THREADED PIPE
GROUT ZONE DEPENDENT UPON DEPTH OF BORING
6 TO 8 INCH NOMINAL DIAMETER BOREHOLE
BENTONITE PELLET SEAL (2 FT. MINIMUM LENGTH)
VARIABLE
2 IN. DIAMETER FLUSH JOINT WELL SCREEN (5 FT. MINIMUM LENGTH)
SAND PACK
5 FT.
VARIABLE
BOTTOM PLUG
CONCRETE PAD
PROTECTIVE CASING
120°
120°
120°
GUARD POST
WELL PIPING
GUARD POST PLAN

However, Teflon is expensive compared to other materials. When situations allow, using Teflon casing and screens in the saturated zone with another suitable material as the upper casing may be a viable, less expensive alternative. The structural properties of Teflon are sufficient for the most exacting environments, giving Teflon a clear advantage over glass. Teflon has not been reported to contribute to or remove organic or inorganic contaminants from aqueous solutions.

### 8.5.6.8.4 Stainless Steel Well Casing

Stainless steel has been the material of choice for casing and screens when subsurface conditions require a durable corrosion-resistant material or when organic adsorption problems might exist. In tests, type 316 stainless steel proved better for use as a well casing than type 304. The principal compositional difference between the two types is the inclusion of 2 to 3 percent molybdenum in type 316. The molybdenum content gives type 316 stainless steel improved resistance to sulfur-containing species and sulfuric acid solutions. Resistance to oxidizing acids is somewhat poorer than other chromium-nickel steels. However, reducing conditions are more frequently encountered in well-casing applications. The type 316 stainless steels are less susceptible to the pitting or pin-hole corrosion caused by organic acids or halide solutions. They are the materials of choice in industries, such as pharmaceuticals, in which excessive metal contamination of process streams must be avoided. Provided that surface coating residues from manufacture or storage are removed, stainless steel well casing, screen, and fittings can be expected to function nearly as well as Teflon in most monitoring applications. Chromium or nickel contamination may result after long exposure to very corrosive conditions. However, physical failure of the casing would probably accompany or precede such an occurrence. Proper well purging before sampling should be sufficient to minimize problems with these materials.

### 8.5.6.8.5 Polyvinyl Chloride Well Casing

Polyvinyl chloride (PVC-Type 1) thermoplastic well casing is composed of a rigid, unplasticized polymer formulation that has many desirable properties for monitoring well construction. It has very good chemical resistance except to low-molecular-weight ketones, aldehydes, and chlorinated solvents. PVC is a close second to Teflon and type 316 stainless steel in its resistance to acid solutions, and it may be expected to outperform any of the ferrous materials in acidic environments of high ionic strength. There may be potential problems when PVC is used in contact with aqueous organic mixtures or under conditions that might encourage leaching of substances from the polymer matrix. Manufacturers, however, do not recommend the use of threaded schedule 40 PVC well casing because of potential mechanical failures. Schedule 80 threaded PVC well casing is sufficiently durable for most well construction applications.

All well casings should, at a minimum, be cleaned with detergent and rinsed with clean water before well construction to remove processing lubricants and release agents. This procedure is particularly necessary for PVC well casing, which may be coated with natural or synthetic waxes, fatty acids, or fatty acid esters. In addition, more thorough cleaning may be required; steam cleaning is often used.

Threaded joints are the preferred means of connecting sections of PVC well casing. In this way, problems associated with use of solvent primers and cements can be avoided. Threaded joints on PVC well casing (or pipe) can be provided in three ways: (1) by solvent cementing a molded thread adapter to the end of the pipe (not recommended), (2) by having molded flush-threaded joints built into each pipe section, and (3) by cutting tapered threads on the pipe with National-Pipe-Thread sized dies. The latter method is recommended only by the industry for schedule 80 PVC well casing or pipe.

Furthermore, manufactured casing and screen is preferable to off-the-shelf PVC pipe. The practice of sawing slots in the pipe (e.g., homemade screens) should be avoided since this procedure exposes fresh surfaces of the material, increasing the risk of releasing compounding ingredients or reaction products. In addition, it is very difficult to properly slot casing materials by sawing them.

### 8.5.6.8.6 Casing Made From Other Ferrous Materials

Ferrous metal well casing and screen materials, with the exception of stainless steels, include carbon steel, low-carbon or copper (0.2 percent) steels, and various steels with a galvanized coating. The carbon steels were formulated to improve resistance to atmospheric corrosion. To achieve this increased resistance, it is necessary for the material to undergo alternate wetting and drying cycles. For noncoated steels buried in soils or in the saturated zone, the difference between the corrosion resistance of either variety is negligible. Both carbon- and copper-steel well casings may be expected to corrode, and corrosion products may include oxides of Fe and Mn (and trace constituents), as well as various metal sulfides. Under oxidizing conditions, the principal products are solid hydrous oxides of these metals, with a large range of potential particle sizes. The solids may accumulate in the well screen, at the bottom of the well, or on the casing surface. The potential also exists for the production of stable colloidal oxide particles that can pass through conventional membrane filtration media. Reducing conditions will generally provide higher levels of truly dissolved metallic corrosion products in well storage waters. Galvanized steels are protected by a zinc coating applied by hot dipping or electroplating processes. The corrosion resistance of galvanized steel is generally improved over conventional steels. However, the products of initial corrosion will include iron, manganese, zinc, and trace cadmium species, which may be among the analytes of interest in a monitoring program.

Corrosion products from conventional or galvanized steels represent a potential source of adsorptive interference. The accumulation of the solid products has the effect of increasing both the activity and the exposed surface area for adsorption, reaction, and desorption processes. Surface interactions can, thereby, cause significant changes in dissolved-metal or organic compound concentrations in water samples. Flushing the stored water from the well casing may not be sufficient to minimize this source of bias because the effects of the disturbance of surface coatings or accumulated products in the bottom of the well would be difficult, if not impossible, to predict. In comparison with glass, plastic, and coated-steel surfaces, galvanized metal presents a rather active surface for adsorption of orthophosphate. The age of the surface and the total area of exposure have been found to be important variables in the adsorption process. However, adsorption is not a linear function of the galvanized-metal surface area.

Field data for conventional and galvanized steels provide additional reasons for the use of caution when choosing these materials for well casings or screens. The water well industry routinely chooses alternative nonconductive or corrosion-resistant materials in areas where normal groundwater conditions are known to attack the common steels. Regional or local practices in the selection of water well construction materials provide valuable preliminary guides for routine monitoring efforts.

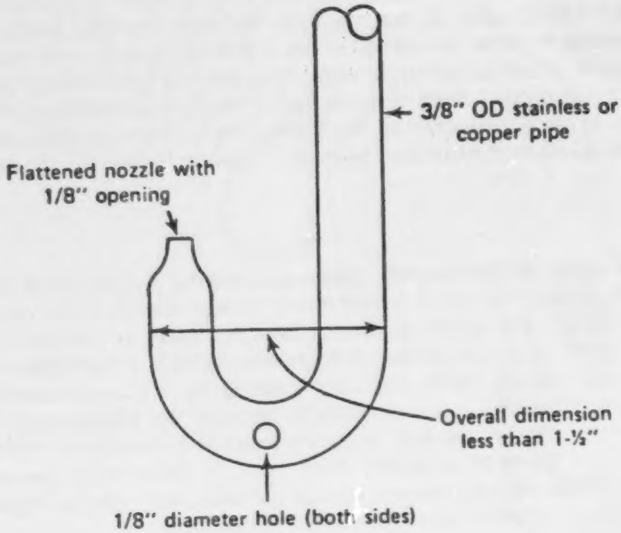
### 8.5.6.8.7 Pumps Used in Development

The large variety of centrifugal, peristaltic, impeller, and submersible pump designs precludes an in-depth discussion of their potential effects on the results of groundwater monitoring efforts. According to the situation, the compatibility of the materials found in high-capacity pumps with subsurface conditions must be carefully considered. The methodology of monitoring well development (see Exhibit 8.5-20) is probably far more critical than the pumping mechanism or water-contacting materials. Use of a Teflon, air-driven, well-development device with filtered air or compressed breathing-grade air minimizes the potential effects on groundwater monitoring.

### 8.5.6.8.8 Grouts, Cements, Muds, and Drilling Fluids

Various drilling aids, cements, and sealant formulations are used to achieve two main goals: (1) to maintain an open borehole in rotary and cable tool operations in unconsolidated formations, and (2) to effect a seal between the surface or overlying formations and the casing or screened intervals so that runoff or other sources of water do not enter the wellbore.

## Exhibit 8.5-20
## AIR-DRIVEN, WELL-DEVELOPMENT DEVICE


3/8" OD stainless or copper pipe
Flattened nozzle with 1/8" opening
Overall dimension less than 1-½"
1/8" diameter hole (both sides)

Water-based drilling fluids are usually used in freshwater applications where the total-dissolved-solids content of groundwater is below 10,000 mg per liter. The fluids are introduced for several purposes including cooling and lubricating the bit, suspending and removing cuttings, stabilizing the borehole by building up a cake on the sides of the hole, and minimizing formation damage that results from water loss or penetration of solids.

There are three main types of freshwater muds: (1) bentonite, attapulgite, or clay-based muds with pH adjusted to between 9 and 9.5 with caustic; (2) polymer-extended clay (organic) muds; and (3) inhibited clay muds that use lignosulfonates or lignin to counteract the effects of contaminants that would otherwise destabilize the slurry and prevent effective cutting removal. The first two types of mud are used most frequently in water-well drilling applications. Both of these mud formulations and a spectrum of combined compositions have been used in the construction of monitoring wells. The main distinction between bentonite and organic muds is the addition of natural or synthetic organic polymers to adjust consistency, viscosity, or surface tension.

For monitoring applications where conditions permit, augering, air-rotary, or clear-water rotary drilling techniques have a distinct advantage over the use of drilling muds. It is preferable to introduce the least possible amount of foreign materials into the borehole. Compressor lubricants for air-rotary rigs may rule out this method for trace organic monitoring work, although filters are available to minimize such problems. In geologic situations in which water-based drilling fluids are a necessity, the predominantly inorganic clay muds are preferable over those containing organic materials, because the introduction of these organics can lead to substrates microbial activity that can seriously affect the integrity of water samples. The decomposition of the organic components of drilling muds may be expected to be a function of their chemical structure, the microbial populations, the presence of nutrients, and various physical and chemical factors controlling the distribution of organic substances in the subsurface.

Inorganic clay muds do have disadvantages. If these materials are not completely removed during the development process, attenuation of organic and metal contaminants in the groundwater may be caused by the highly sorptive bentonite muds. In zones where concentrations of contaminants are in the low parts per billion (ppb) range, this phenomenon may be very important.

Seals, grouts, and cements are the primary safeguards against the migration of water from the surface and from overlying or adjacent formations into monitoring wells. Faulty seals or grouts can seriously bias the analytical results on water samples from the formation of interest, particularly if water quality conditions vary or surface soils are badly contaminated. The impact of leaking seals may go far beyond the realm of analytical interferences or nonrepresentative samples. A leaky wellbore may act as a conduit to permit rapid contaminant migration that otherwise would not have occurred. This aspect of a groundwater monitoring program should not be left to an unsupervised drilling crew, and last-minute substitutions for preferred materials should not be made. Surface seals must also be completed with concern for the security at the wellhead by including casing sheaths and locking caps. Most seals between the formation of interest and regions above or below are made by adding clay materials or cement.

Bentonite clay can increase in volume by 10 to 15 times after wetting with deionized water. Variations in the composition of the contacting solution can severely reduce the swelling of clay seals. Swelling volumes of 25 to 50 per cent of the maximum values are not uncommon. The organic content of the solution in contact with the clay can have a dramatic effect on the integrity of the seal. Organic compounds can cause significant disruption of normal shrinking, swelling, or dehydrating of the clay lattice during alternate wetting and drying cycles. Alcohols, ketones, and other polar organic solvents have a significant potential for these changes. On the microscopic level, these phenomena can materially increase the permeability of the clay seal. This active area of research has wide application in the fields of well construction, landfill liners, and slurry or grout cutoff walls. Macroscopic changes in the permeability of clay or cement seals can occur because of solution channeling by aggressive solvents, compaction or subsidence, and freezing and thawing processes at the surface. Chemical-resistant and expanding cement formulations effectively minimize these problems.

### 8.5.6.8.9 Evaluation of Sample Collection Materials

The choices of sample collection devices, procedures, and all materials that ultimately contact water samples are probably the most critical considerations in a groundwater monitoring program. The monitoring program planner must evaluate the collection mechanisms and all materials to determine whether they would introduce interference or bias into the final analytical result. For example, a collection mechanism that creates turbulent transfer of the sample and the opportunity for gas exchange (e.g., air-lift pumping mechanisms) is clearly inappropriate in sampling for volatile organic compounds and pH- or redox-sensitive chemical species.

The following are desirable attributes for sample collection materials:

- Durability
- Ability to be decontaminated and cleaned effectively to prevent cross-contamination between sampling points (i.e., low permeation of material by contaminants)
- Verified low potential for introducing contamination, bias, or interferences into the analytical results

Each of these attributes plays an important role in the overall performance of monitoring efforts and bears directly on the successful retrieval of representative water samples. The combinations of components in pumps (or other samplers) and the properties of polymeric and elastomeric materials for tubing or transfer lines make the selection of the sample collection apparatus difficult.

Apart from the actual sampling mechanisms, the materials used for a sampler are of prime importance. Fortunately, most devices are constructed in different models for specific situations. For example, bailers are fabricated in Teflon, stainless / Teflon, stainless / PVC 1, or PVC 1. These materials satisfy the major specifications. Problems arise with nonrigid components of samplers. A single pair of O-rings may limit the application of a device.

Teflon incorporates most of the characteristics of an ideal sampling material. It is, however, a difficult material to machine, and threaded components are easily damaged. For chemical resistance and durability, several materials other than stainless steel may be expected to perform satisfactorily in low-organic environments. These materials include polypropylene, linear polyethylene, plasticized PVC, Viton, and conventional polyethylene. Viton is a preferred material for elastomeric parts since it may be expected to give improved chemical resistance over silicone and neoprene.

Tubing and transfer lines are available in a variety of polymeric or elastomeric materials. Certain applications (e.g., peristaltic or bladder pumps) demand a high- resiliency material, and it may be necessary to sacrifice chemical resistance to achieve the desired structural performance. The bulk of common tubing materials, except for Teflon, contains a wide range of additives. Plasticizers, lubricants, antistatic agents, tackifiers, and other ingredients may be present in flexible synthetic materials. In general, true polymers (e.g., polyolefins like polyethylene and polypropylene) contain much lower amounts of such ingredients. Formulations change frequently as manufacturers strive to keep production costs low, so a particular material may show significant variation from lot to lot. Plasticizers are frequently present at levels between 15 and 50 percent of the total weight of flexible products. As a result of this fact and because of the widespread use of plastic, major plasticizers, such as phthalate esters, have been consistently identified in environmental samples.

Teflon is the tubing material of choice in monitoring for low-level organic compounds in complex, chemically aggressive environments. Polyethylene and polypropylene are clearly superior plastic materials when Teflon is not cost-effective. Silicone rubber tubing for moving components is a special case in which alternate choices of material may not be feasible. The material is available in several grades that have widely varying compositions and additives. Metallic contamination from certain laboratory grades of silicone rubber tubing can be quite serious at the ppb level. Iron and zinc concentrations two to five times those of control samples are not uncommon even after short contact times. Medical grade silicone rubber tubing is, however, relatively free of unreacted organic initiators (peroxides) or zinc. Silicone rubber tubing is generally a poor choice of sampler for detailed organic analytical schemes. Other elastomeric materials, such as natural rubber, latex, neoprene, or chloroprene, are not recommended for transfer lines or surfaces that contact groundwater samples.

Little information is available on the performance of flexible materials in groundwater applications. From the available observations, Teflon, polypropylene, and linear polyethylene may be expected to outperform plasticized PVC, since they have superior chemical resistance over a range of environments and are less likely to cause contamination or bias problems. Microbial transformation of additives in plastics introduces another dimension to the problem posed by materials with high concentrations of additives. There are a number of reports on the microbial colonization of flexible PVC and the degradation of plasticizers from the polymer matrix.

### 8.5.6.9 Groundwater Sampling Considerations

The importance of proper sampling of wells cannot be overemphasized. Even though the well being sampled may be correctly located and constructed, special precautions must be taken to ensure that the sample taken from that well is representative of the groundwater at that location and that the sample is neither altered nor contaminated by the sampling and handling procedures.

To select proper sampling procedures, it is essential that sampling objectives be firmly established before field activities begin. These objectives will dictate the parameters to be measured, the reliability of the water quality data, and the analytical methodology, which determines the sampling procedures necessary to meet these objectives. In addition, the physical limitations of the well, depth to water, length and location of the well screen, availability of power, and accessibility of the well site all have a bearing on the practical application of various sampling procedures.

Sample withdrawal mechanisms should be completely inert; economical to manufacture; easily cleaned, sterilized, and reused; able to be operated at remote sites in the absence of external power sources; and capable of delivering continuous but variable flow rates for well flushing and sample collection. Sampling equipment is described in Subsection 8.1. The physical characteristics of the well largely determine the sampling mechanism to be used for inorganic and nonvolatile organic analysis. Volatile organics are usually sampled with Teflon or stainless steel bailers, and extra care should be used to handle samples.

Before use, all sampling devices should be carefully cleaned. A dilute hydrochloric acid rinse followed by successive rinses with deionized water, acetone, and distilled organic-free water is routinely used. In badly contaminated situations, a hot-water detergent wash before the above rinsing procedure may be necessary. Hexane rinses before the final distilled inorganic water rinse will aid in the removal of sparingly soluble organic materials before sampling for low-level organic pollutants.

The static water level should be measured and recorded at the time of sampling. Water levels can be obtained using one of the devices discussed previously. In older wells not previously sampled, the bottom of the well should be established by sounding.

To obtain a representative sample of the groundwater, a volume of stagnant water in the wellbore must first be purged. The recommended length of time required to pump or bail a well before sampling depends on the well and aquifer characteristics, the type of sampling equipment being used, and the parameters being sampled. A common procedure is to pump or bail the well until at least three to five bore-volumes have been removed. A more reliable method is to pump or bail until the measurements of pH, temperature, and specific conductance have stabilized over three well volumes.

In the case of monitoring wells that will not yield water at a rate adequate to be effectively flushed, different procedures must be followed. One suggested procedure includes removing water to the top of the screened interval to prevent the exposure of the gravel pack or formation to atmospheric conditions. The sample is then taken at a rate that would not cause rapid drawdown. The wells may also be pumped dry and allowed to recover. The samples should be collected as soon as a volume of water sufficient for the intended analytical scheme reenters the well. Exposure of water entering the well for periods longer than 2 to 3 hours may render samples unsuitable and unrepresentative of water contained within the aquifer system. In these cases, it may be desirable to collect small volumes of water over a period of time, each time pumping the well dry and allowing it to recover. Whenever full recovery exceeds 3 hours, samples should be collected in order of their volatility as soon as sufficient volume is available for a sample for each analytical parameter or compatible set of parameters. Parameters that are not pH-sensitive or subject to loss through volatilization should be collected last. Few reliable data exist on when to choose one sampling method over another in "tight" formations.

To collect a sample for other than volatile organics analysis, the cap should be removed carefully from the previously decontaminated sample bottle. The person doing the sampling should not lay the cap down or touch the inside of the cap. At no time should the inside of the bottle come in contact with anything other than the sample. The bottle should be filled, in a manner to minimize aeration, to within 2.5 cm (1 inch) of the top. The cap should be replaced carefully, and the bottle should be placed in a cooler (4°C to 10°C) unless the sample is going to be processed immediately in the field. Sampling equipment should be decontaminated between samples. For volatile organic analysis, the bottles should be filled in a manner to minimize aeration of the samples so that no headspace exists in the bottle. No air bubbles should be trapped in the bottle.

## 8.5.7 Information Sources

Barcelona, M.J., J.P. Gibb, and R.A. Miller. *A Guide to the Selection of Materials for Monitoring Well Construction and Ground-Water Sampling.* ISWS Contract Report 327. Champaign, Illinois: Illinois State Water Survey. 1983. 78 pp.

Gillham, R.W., M.L. Robin, J.F. Banker, and J.A. Cherry. *Groundwater Monitoring and Sample Bias.* API. 1983.

Scalf, M.R., J.F. McNoll, W.N. Dunlop, R.L. Cosby, and J. Fryberger. *Manual of Groundwater Sampling Procedures.* NWWA/EPA Series. Ada, Oklahoma: U.S. Environmental Protection Agency.

U. S. Environmental Protection Agency. *Practical Guide to Groundwater Sampling.* EPA 600/2-85-104. Ada, Oklahoma: NTIS, ERL.

U.S. Environmental Protection Agency. *RCRA Groundwater Monitoring Technical Enforcement Guidance Document*. EPA 530/SW-86-055 NTIS. September 1986.

# SECTION 9

# EARTH SCIENCES LABORATORY PROCEDURES

## 9.1 SCOPE AND PURPOSE

Section 9 identifies the laboratory procedures used to determine the physical and chemical properties of soil materials. Procedures are given for volumetric, strength, and transport relationship tests and for testing chemical properties.

The purpose of Section 9 is to provide general guidance for the planning and implementation of laboratory testing of earth science materials for hazardous waste projects. This section provides both a broad overview of the types of routine laboratory techniques available for use and a brief, general discussion of their purpose and applicability. It also lists references to specific testing techniques and standards, where available. The reader should refer to Exhibit 9-1 for an index of test parameters as related to test methods.

Test types and techniques presented herein cover routine methods that may be applicable at the site investigation, feasibility study, predesign, design, or construction phases of hazardous waste projects.

This section is not intended to be all-inclusive, because the application of laboratory testing to a particular project, demands careful and knowledgeable planning and experimental design. Detailed specification is required for all work, for quality assurance (QA) and/or sampling plans, and for each laboratory testing request, both for the U.S. EPA Contract Laboratory Program (CLP) and for private laboratories. The specifications should be included in work plan, QA plan, and/or sample plan.

## 9.2 DEFINITIONS

Definitions may be found in ASTM D653-82, *Standard Definitions of Terms and Symbols Relating to Soil and Rock Mechanics* and in some of the individual test method terminology subsections.

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. This person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

## 9.3 APPLICABILITY

Soil samples collected during field investigations may be analyzed using the procedures identified in this section. The analyses will determine the physical and chemical soil properties listed here. The results of these procedures can be used in soils engineering determination, contaminant migration evaluation, and design considerations. Health and safety aspects of using these test procedures on contaminated materials must be addressed in a site-specific, or laboratory health and safety plan.

## Exhibit 9-1
## TEST PARAMETER VERSUS TEST METHOD

| | | |
|---|---|---|
| 9.6.3 | Physical Properties | |
| 9.6.3.1 | Soil | |
| 9.6.3.1.1 | Index Property Tests | |
| | Visual Classification | ASTM D 2488-84 |
| | Moisture Content | ASTM D 2216-80 |
| | Atterberg Limit | ASTM D 4318-84 |
| | Grain Size | ASTM D 422-63 |
| | Specific Gravity | ASTM D 854-83 |
| | Soil Classification | ASTM D 2487-85 |
| | Sand Equivalent | ASTM D 2419-74 |
| | Centrifuge Moisture | ASTM D 425-79 |
| | Capillary-Moisture Relationship | ASTM D 2325-68 |
| | | ASTM D 3152-72 |
| 9.6.3.1.2 | Density Tests | |
| | Unconfined Compression | ASTM D 1587-83 |
| | | ASTM D 3550-84 |
| | Moisture-Density Relationship | ASTM D 698-78 |
| | | ASTM D 1557-78 |
| | Relative Density | ASTM D 4253-83 |
| | | ASTM D 4254-83 |
| 9.6.3.1.3 | Strength Tests | |
| | Unconfined Compression | ASTM D 2166-85 |
| | Direct Shear | ASTM D 3080-72 |
| | Triaxial Compression | ASTM D 2850-82 |
| | Vane Shear | ASTM D 2573-72 |
| | Moisture Penetration Resistance | ASTM D 1558-84 |
| | Bearing Ratio | ASTM D 1883-73 |
| 9.6.3.1.4 | Deformation Tests | |
| | One-Dimension Consolidation | ASTM D 2435-80 |
| | Swell Test | ASTM D 4546--85 |
| 9.6.3.1.5 | Permeability Tests | |
| | Undisturbed Samples (cohesive) | |
| | Recompacted Samples | ASTM D 2434-68 |
| 9.6.3.2 | Rock | |
| 9.6.3.2.1 | Index Property Tests | |
| | Apparent Specific Gravity | ASTM C 127-83 |
| | Soundness | ASTM C 88-83 |
| 9.6.3.2.2 | Strength Tests | |
| | Uniaxial Compressive Strength | ASTM C 170-85 |
| | Direct Tensile Strength | ASTM D 2936-84 |
| | Splitting Tensile Strength | ASTM D 3967-81 |
| | Flexural Strength | ASTM C 99-85 |

## Exhibit 9-1
## (continued)

| | | |
|---|---|---|
| 9.6.3.3 | Materials | |
| 9.6.3.3.1 | Concrete | |
| | Compressive Strength | ASTM C 39-83 |
| | Extrained Air | ASTM C 231-82<br>ASTM C 173-78 |
| | Flexural Strength | ASTM C 78-84<br>ASTM C 293-79 |
| | Specific Gravity | ASTM C 642-82 |
| | Splitting Tensile Strength | ASTM C 496-85 |
| 9.6.3.3.2 | Soil Cement | |
| | Miscellaneous | ASTM D 2901-82<br>ASTM D 806-74<br>ASTM D 1632-63<br>ASTM D 1633-84<br>ASTM D 1634-63<br>ASTM D 1635-63<br>ASTM D 558-82<br>ASTM D 559-82<br>ASTM D 560-82 |
| 9.6.3.3.3 | Portland Cement | |
| | Blended Hydraulic Cement | ASTM C 150-85a |
| 9.6.3.3.4 | Asphalt Cement | |
| 9.6.3.3.5 | Asphalt Stabilized Soils | ASTM D 4223-83 |
| 9.6.3.3.6 | Geotextiles | |
| | Fabric Weight | ASTM D 3773-84<br>ASTM D 3774-84<br>ASTM D 3775-85<br>ASTM D 3776-85 |
| | Fabric Thickness | ASTM D 3777-64 |
| | Grab Strength and Elongation | ASTM D 1682-64 |
| | Abrasion Resistance | |
| | Puncture Resistance | ASTM D 751-79 |
| | Mullen Burst Strength | ASTM D 3786-80a |
| | Trapezoid Tearing Strength | ASTM D 1117-80 |
| | Equivalent Opening Size (EOS) | U.S. Army COE |
| | Planar Flow | |
| | Normal Permeability | |
| | Coefficient of Friction (soil to fabric) | |
| | Coefficient of Friction (fabric to fabric) | |
| | Alkali or Acid Stability | |
| | Thermal Shrinkage | |
| | Ultraviolet Stability | |

## Exhibit 9-1
## (continued)

| | | |
|---|---|---|
| 9.6.3.3.7 | Geomembranes | |
| | Thickness | ASTM D 1593-81<br>ASTM D 412-83 |
| | Specific Gravity | ASTM D 792-66 |
| | Tensile Strength | ASTM D 882-83<br>ASTM D 412-83<br>ASTM D 638-84 |
| | Elongation | ASTM D 882-83<br>ASTM D 412-83<br>ASTM D 638-84 |
| | Tear Resistance | ASTM D 1004-66<br>ASTM D 624-86<br>ASTM D 751-79 |
| | Dimensional Stability | ASTM D 1204-84 |
| | Bonded Seam Strength | ASTM D 3083-79<br>ASTM D 751-79 |
| | Peel Adhesive | ASTM D 413-82 |
| 9.6.4 | Chemical Properties of Soil and Rock | |
| 9.6.4.1 | Waste Evaluation Procedures | |
| 1.1 | Ignitability | EPA SW-846 1010, 1020 |
| 1.2 | Corrosivity | EPA SW-846 1110 |
| 1.3 | Reactivity | EPA SW-846 |
| 1.4 | Extraction Procedure | EPA SW-846 1310 |
| 1.5 | Mobility | EPA SW-846 1410 |
| 9.6.4.2 | Pollutant Analysis | |
| 2.1 | Organics | EPA SW-846 8010-8310<br>3510-3550 |
| 2.2 | Metals | EPA SW-846 7040-7951<br>3010-3060 |
| 2.3 | Total and Amenable Cyanide | EPA SW-846 9010 |
| 2.4 | Total Organic Halides (TOX) | |
| 2.5 | pH | Ref. |
| 2.6 | Lime Requirement | Ref. |
| 9.6.4.3 | Other Tests | |
| 3.1 | Cation Exchange Capacity | Ref. |
| 3.2 | Extractable Cations | Ref. |
| 3.3 | Exchangeable Hydrogen | Ref. |
| 3.4 | Total Soluble Salts--<br>Electrical Conductivity | Ref. |
| 3.5 | Carbon<br>Total Organic and Inorganic | U.S. Army COE |
| 3.6 | Sulfides | EPA SW-846 9030 |
| 3.7 | Total Nitrogen | Ref. |
| 3.8 | Extractable Phosphorus | Ref. |
| 3.9 | Total Phosphorus | U.S. Army COE |
| 3.10 | Mineralogy | Ref. |

## Exhibit 9-1
## (continued)

**9.6.5 Compatibility Testing**
**9.6.5.1 Soil**
  - **1.1 Clay**
  - **1.2 Silt**
  - **1.3 Sand**
  - **1.4 Gravels/Aggregates**

**9.6.5.2 Rock**

**9.6.5.3 Materials**
  - **3.1 Concrete**
  - **3.2 Soil-Cement**
  - **3.3 Portland Cement**
  - **3.4 Asphalt Cement**
  - **3.5 Asphalt Stabilized Soils**
  - **3.6 Metal Products**
  - **3.7 Plastic Products**
  - **3.8 Wood Products**
  - **3.9 Geotextiles**
  - **3.10 Geomembranes**
  - **3.11 Synthetic Drainage Media**

**9.6.6 Laboratory/Analysis Records**

**9.6.6.1 Sample Log**
  - **6.1 Data Sheets**
  - **6.2 Recordkeeping**

## 9.4 RESPONSIBILITIES

The SM or designee is responsible for ensuring that these procedures are followed. The SM may appoint the project geotechnical engineer or soil scientist as the responsible person.

## 9.5 RECORDS

Records will be kept in a bound notebook with numbered pages (see also Sections 6 and 17). Information to be recorded includes the following:

- Project name and number; EPA work authorization number
- Date of sample collection
- Collector's name
- Sample location and depth
- Method of collection (see Section 8, Earth Sciences)
- Date of laboratory analysis
- Name of laboratory

Other laboratory records specific to certain test procedures are discussed in the following subsections.

## 9.6 PROCEDURES

### 9.6.1 Introduction

Most of the procedures described below are derived from the 1984 *American Society of Testing and Materials (ASTM) Book of Standards*, Section 4 – Construction, Volume 04.08 *Soil and Rock; Building Stones* (ASTM, 1916 Race Street, Philadelphia, Pennsylvania 19103. 734 pages). Revisions to some of these procedures are due soon. In addition, certain procedures listed below have been found to be not wholly satisfactory for work on highly contaminated materials. Users of this compendium should review the most recent ASTM procedures for changes. Applicable ASTM standards should be included in work, QA, and sample plans. The subsection below discusses the evaluation of the suitability of a laboratory to conduct the procedures, and it discusses the various tests. The standards are listed in the categories of sample handling; physical tests (volumetric, strength, and transport relationships); chemical tests (mineralogy, cation exchange capacity, and distribution coefficient); and laboratory records.

## 9.6.2 Laboratory Selection

### 9.6.2.1 Evaluation of Agencies (Laboratories)

The evaluation of agencies engaged in testing and inspecting materials used in engineering design and construction is important to quality assurance goals.

This subsection discusses criteria for the evaluation of a testing or inspection agency's organizational, human, and physical resource capabilities. These criteria require disclosure of those factors on which the objectivity of the agency can be judged.

The reader should refer to ASTM D 3740-80 *Standard Practice for the Evaluation of Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction* and ASTM E 329-77 (1983) *Standard Recommended Practice for Inspection and Testing Agencies for Concrete, Steel, and Bituminous Materials as Used in Construction.*

### 9.6.2.2 Sample Integrity

Methods of sample handling in the laboratory may affect the physical and chemical state of samples and the reliability of the test results. Special attention should be given to how samples are transported, stored, and prepared for laboratory testing. Guidance is available in some ASTM standards for particular tests.

Provisions for handling samples generally include the following:

- Temperature and humidity controls in the laboratory environment and storage areas
- Provisions for opening and resealing sample containers
- Tools for trimming and preparing samples

Where sample quantity is limited, it may be possible to perform sequence testing so that the same sample can be used in multiple analyses. However, some sample types and some tests preclude reuse in subsequent analyses because of irreversible alteration of the sample.

### 9.6.2.3 Laboratory Safety

The safe handling of samples in the laboratory depends on several factors that include design of the laboratory facilities; laboratory policies and procedures for sample handling, analysis, and disposal; and training of laboratory personnel in the safe handling of samples, personal protection, and emergency procedures.

Earth sciences laboratories engaged in analyzing hazardous materials should have secure, ventilated storage and disposal areas with controlled access; readily available safety equipment (e.g., fire extinguishers, self-contained breathing apparatus, safety shower, eye wash station, first aid kit); ventilated hoods for the handling and testing of samples; an emergency ventilation system in case of accidental release of hazardous gases; routine inspection and maintenance of laboratory equipment (including safety equipment); fire-resistant walls, doors, and windows; an emergency alarm system; and access to a telephone with emergency numbers displayed.

Laboratory policies should be established for using protective clothing and equipment; appropriate training and medical surveillance of employees; collecting and disposing of hazardous or toxic wastes; monitoring the laboratory atmosphere and equipment; investigating and reporting laboratory accidents; and working alone. Spill prevention plans and a list of emergency procedures should be placed in a prominent place, and employees should be familiar with the procedures.

## 9.6.3 Physical Properties

### 9.6.3.1 Soil

#### 9.6.3.1.1 Index Property Tests

Visual Classification

**Purpose:** The visual classification of soils allows convenient and consistent comparison of soils using a standard descriptive method. The use of this classification method provides a basis for comparing soils from widespread geographic areas.

**Synopsis:** By visual observation, a soil is assigned to one of three primary groups: coarse-grained soils (gravels and sand); fine-grained soils (silts and clays); and organic soils (soils containing organic matter, such as decayed roots, leaves, grasses, and other fibrous vegetable matter). After the soil is assigned to one of the primary groups, other visual and physical characteristics are observed, such as color, odor, moisture condition, and structural characteristics.

**Methods:** ASTM D 2488-84, Standard Practice for Description of Soils (Visual-Manual Procedure).

**Limitations and Precautions:** The ability to visually classify soils requires practice and experience. Laboratory test ASTM D 2487-85 should verify visual classifications.

Moisture Content

**Purpose:** The moisture content test determines the mass of water contained in a given mass of soil. The results are usually presented as the mass of water divided by the mass of dry solids, expressed as a percentage. Moisture content (along with unit weight and specific gravity of solids) provides the basis for determining the phase relationships of a soil. A comparison of the field moisture content of a soil with its index properties (such as Atterberg Limits) may be useful in estimating soil consistency, compressibility, and strength.

**Synopsis:** A sample of the soil is weighed as received, dried for 24 hours at 105°C, and then weighed again. The difference in mass is attributable to water loss during drying. Results are presented as the water mass divided by the dry solids mass, expressed as a percentage.

**Methods:** ASTM D 2216-80, Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures.

**Limitations and Precautions:** It is important to prevent moisture content changes during sampling, shipping, and handling. Precautions may include sealing the sample in wax, foil, plastic, or a combination thereof or shipping the entire sample in the Shelby tube used for sampling.

Organic soil that contains items such as wood, fibers, or decayed vegetation demands careful monitoring, since drying at high temperature may destroy some of the organic matter. Organic chemicals may be driven off and their mass mistaken as water.

Atterberg Limits

**Purpose:** The Atterberg Limits include liquid limit (LL), plastic limit (PL), and plasticity index (PI), which are used for the following:

- To assist in classification of soils
- To indicate soil consistency (when compared with natural moisture content)
- To provide correlation to soil properties, including compressibility and strength

**Synopsis:** LL is the moisture content at which a soil becomes liquid and flows to close standard-size groove when subjected to 25 impacts in the standard test device. PL is the moisture content at which soil becomes plastic, as demonstrated by the moisture content causing incipient crumbling to occur in the soil when it is rolled into 1/8-inch threads. PI is the difference between the LL moisture content and the PL moisture content; it represents the range between plastic and liquid states of the soil.

A soil sample is prepared by starting the test at either natural or air-dried moisture content.

**Methods:** ASTM D 4318-84, Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

**Limitations and Precautions:** Soils may exhibit different liquid and plastic limits if they are prepared from air-dried or natural moisture conditions. The liquid limit device must be calibrated before use. Operator error in applying insufficient or excessive pressure or improper rolling rates while performing the plastic limit procedure may affect results.

Grain Size

**Purpose:** Grain size distribution is used to assist in classifying soils and to provide correlation with soil properties that include permeability and capillarity. In addition, grain-size analyses are essential for adequate assessment and design of such specific features as granular drains, filters, well screens, and gravel pack materials.

**Synopsis:** Three general procedures used to determine the grain-size distribution of soil include sieve analysis, hydrometer analysis, and a combined analysis. A sieve analysis consists of shaking soil through a stack of progressively finer meshed screens, each with a known opening size, and determining the portion (by weight) of particles retained on each sieve. The hydrometer analysis is based on Stoke's Law for the velocity of a freely falling sphere; the method determines the settling rate of soil particles by measuring the density of the soil-water solution and calculating the particle size in suspension at particular time intervals. The combined procedure consists of both the sieve and hydrometer analyses to determine the grain size distribution throughout the full range of particle sizes.

**Methods:** ASTM D 422-63, (reapproved 1972), *Method for Particle-Size Analysis of Soils.*

**Limitations and Precautions:** Because the hydrometer method is extremely sensitive to a number of variables, the accuracy of fine-grained soils distribution is more questionable than that of the coarser-grained soils. The hydrometer analysis may be more sensitive to interferences from hazardous materials than the sieve analysis.

Specific Gravity

**Purpose:** The specific gravity of soil particles is used in determining the phase relationships of air, water, and solids in soils. For example, specific gravity can be used to determine unit weights that are used in pressure, settlement, and stability problems.

**Synopsis:** The specific gravity of a soil is the ratio of the weight in air of a given volume of soil particles to the weight in air of an equal volume of distilled water at 4°C. A pycnometer (volumetric bottle) is calibrated, and a known weight of a soil slurry is introduced into the pycnometer. The pycnometer is evacuated of dissolved air. It is then weighed, and the temperature of the slurry is recorded. The specific gravity of the soil particles is calculated using the dry weight of the original soil sample; the weight of the pycnometer, soil, and water; and the weight of the pycnometer plus water.

**Methods:** ASTM D 584-84, Test Method for Specific Gravity of Soils.

**Limitations and Precautions:** It is generally recommended that soils containing soluble salts should be slurried using kerosene. This, coupled with any hazardous waste within the soil being tested, may greatly alter the specific gravity as calculated. Also, kerosene and hazardous materials may be susceptible to fire or explosion. This test is susceptible to sources of error in the measurement of weights and temperature because the equation used involves the differences in weights, which are small compared to the weights themselves.

Soil Classification Systems

**Purpose:** Soil classification systems attempt to group soils having similar engineering behavior (based on index tests). A number of classification systems have been developed, each for a specific application. For example, the U.S. Army Corps of Engineers (COE) has a classification system based on the frost susceptibility of soils. The Bureau of Public Roads has a classification based on the applicability of soils to highway construction. The Federal Aviation Administration (FAA) and the COE have developed a classification system for soils used in airfield construction. The Bureau of Reclamation and the COE have developed a classification system intended for use in all types of engineering problems that involve soils. The system most generally accepted for a wide range of engineering applications is the Unified Soil Classification System (USCS).

**Synopsis:** Soil classification systems generally use index test methods to permit rational grouping of soils. Some of the specific index test methods that are applicable to soil classification are discussed elsewhere in this section (see Index Property Tests, Subsection 9.6.3.1.1).

**Methods:** ASTM D 2487-85, Test Method for Classification of Soils for Engineering Purposes. Additional methods are forthcoming.

**Limitations and Precautions:** Caution must be used in solving problems of flow, strength, compressibility, and stability strictly on the information provided by a soil classification system. Many empirical correlations between indexes and soil properties and behavior have large deviations.

Sand Equivalent

**Purpose:** A sand equivalent test is performed to allow an estimation of the amount of clay-like or plastic fines in a granular soil. The test takes little time to perform and, therefore, may be used in either the field or the laboratory as a quick check on the relative amount of fines in a granular soil. The results of the test can be used for controlling types of materials placed in earthworks.

**Synopsis:** A known volume of granular soil is placed with a flocculating agent into a graduated cylinder and is shaken, which loosens clay-like or plastic fines. The material is then irrigated with more flocculating agent. The granular soil settles, and the clay-like particles are forced into suspension. The height of the granular soil and the flocculated clay-like particles are measured. The sand equivalent is the ratio of the height of sand to the height of clay-like material, times 100.

**Methods:** ASTM D 2419-74 (reapproved 1979), Test Method for Sand Equivalent Value of Soils and Fine Aggregate.

**Limitations and Precautions:** The test results should be interpreted as an empirical value of the relative amount of fine material in the sample tested. Sample selection and variations in segregation as a result of handling may significantly alter test results. Hazardous materials within the sample in combination with the flocculating agent may create unusable results. This test is not intended to replace either ASTM D 422 or D 1140.

### Centrifuge Moisture

**Purpose:** A centrifuge moisture test is performed to estimate the air-void ratio, the water-holding capacity, or the specific retention of a soil. Test results are used in the phase relationships of soils, which can be used as index properties. The results are also used in estimating the amount of water that can be removed from a soil in the laboratory or in situ, by gravity drainage.

**Synopsis:** Duplicate soil samples are obtained, prepared, and saturated with distilled water. They are then placed in a centrifuge, held at a constant temperature, and accelerated to a force equal to 1,000 times the force of gravity. The speed of the centrifuge is held constant for 1 hour; the specimens are removed and the mass of dry soil is obtained.

**Methods:** ASTM D 425-79, Test Method for Centrifuge Moisture Equivalent of Soils.

**Limitations and Precautions:** The test results are affected by temperature and by the equipment used in the test. Results are for extremely small samples, and extrapolation to in situ soils or consideration of scale effects must be used with proper engineering judgment.

### Capillary-Moisture Relationships

**Purpose:** The capillary-moisture test is performed to estimate the specific retention of a soil. Specific retention is also referred to as field capacity or water-holding capacity. The specific retention is used in determining the specific yield of soil, which is the ratio of the drainable volume to the bulk volume of a soil material.

**Synopsis:** A saturated soil sample is placed in contact with a saturated porous plate or membrane. A pressure drop is induced across the plate or membrane. The soil samples establish equilibrium with the plate or membrane, and water that is held at a tension less than the pressure drop will flow out of the soil through a drain hose. When equilibrium is reached for a given tension, flow will stop and the moisture content of the sample can be determined. A series of tests is performed at varying tensions, and a curve of moisture content versus tension is prepared.

**Methods:** ASTM D 2325-68 (reapproved 1981), Test Method for Capillary Moisture Relationships for Coarse and Medium-Textured Soils by Porous-Plate Apparatus; and ASTM D 3152-72 (reapproved 1977), Test Method for Capillary Moisture Relationship for Fine-Textured Soils by Pressure-Membrane Apparatus.

**Limitations and Precautions:** Results of the test provide only an indication of the capillary-moisture relationship of the soil tested. Extrapolation of laboratory results to field or in situ conditions must be used with proper engineering judgment.

### 9.6.3.1.2 Density Tests

Undisturbed Samples

**Purpose:** Undisturbed unit weight or density of undisturbed samples is used to determine the phase relationships for soils and for correlation to soil properties.

**Synopsis:** A sample of undisturbed soil is obtained in conformance with the appropriate sampling standards described below. The sample is weighed and measured for length, width, and height. The density (unit weight) is calculated as the sample weight divided by sample volume. With the moisture content of the sample, the dry unit can be calculated.

**Methods:** ASTM D 1587-83, Practice for Thin-Walled Tube Sampling of Soils; and ASTM D 3550-87, Practice for Ring-Lined Barrel Sampling of Soils.

**Limitations and Precautions:** The term "undisturbed" is a relative term. Disturbance may occur during sampling, shipment, and sample preparation. This disturbance may or may not be of consequence in determining the unit weight of the soil. Proper engineering judgment and familiarity with the type of soil sampled will minimize the effects of sample disturbance.

Moisture-Density Relationships

**Purpose:** Laboratory determinations of moisture-density relationships are used in the phase relationships of soils, in specifying density for other laboratory tests, and for comparing in-place field densities to laboratory standard curves for construction of earthwork control.

**Synopsis:** A soil sample is obtained and divided into at least four specimens. Each specimen is prepared by adjusting the moisture content and compacting into a volumetric mold using a specified energy. A relationship is developed between the dry unit weight and the percentage of moisture content for each specimen. The results are generally presented in the form of a curve showing the relationship of dry density versus moisture content.

**Methods:** ASTM D 698-78, Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb Rammer and 12-in. Drop; and ASTM D 1557-78, Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb Rammer and 18-in. Drop.

**Limitations and Precautions:** The methods used to determine compaction densities are generally applicable to fine-grained soils or to those that are not free draining. The methods have been used on free-draining soils. However, a well-defined relationship between soil density and moisture may not exist, and engineering judgment is required to interpret the results.

Relative Density

**Purpose:** The relative density expresses the degree of compactness of a soil with respect to minimum and maximum index densities.

**Synopsis:** The minimum index density is obtained by pouring the soil as loosely as possible into a volumetric mold. Weight and volume relationships are determined, and a minimum density is obtained. The maximum index density is obtained by placing the soil in a volumetric mold, placing a surcharge weight on top of the soil, and then densifying the soil by vibration using a specified amplitude and frequency.

**Methods:** ASTM D 4253-83, Test Methods for Maximum Index Density of Soils Using a Vibratory Table; and ASTM D 4254-83, Test Methods for Minimum Index Density of Soils and Calculation of Relative Density.

**Limitations and Precautions:** The determination of relative density is subject to variations in the vibration apparatus used and in the degree of care used to determine minimum density. Materials with greater than approximately 8 per cent fines (i.e., fines are silts and clays) are generally not appropriate for the relative density determination; other methods of determining density should be used (i.e., laboratory moisture-density relationships).

### 9.6.3.1.3 Strength Tests

Unconfined Compression

**Purpose::** The unconfined compressive strength provides an indication of the strength of the soil in unsaturated, undrained conditions without lateral confinement on the sample. Unconfined compression test results assist in evaluating the consistency of soils and can be used in stability analyses of foundations, excavations, and embankments.

**Synopsis:** A cylindrical soil sample is prepared and loaded in uniaxial compression to failure. The unconfined compressive strength is determined as the peak uniaxial stress that is twice the maximum shear stress.

**Methods:** ASTM D 2166-85 (reapproved 1979), Test Methods for Unconfined Compressive Strength of Cohesive Soil.

**Limitations and Precautions:** Strength estimates based on the unconfined compression test are only approximate estimates of the in situ strength of soil because of effects of disturbance, lack of confinement, and unsaturation in test samples. Strain rates, sample preparation, and sample disturbance may alter the results of the test.

Direct Shear

**Purpose:** The results of the direct shear test are generally used in stability and strength analyses for foundations, excavations, and embankments.

**Synopsis:** A soil sample is placed and consolidated within a direct shear box, which allows horizontal loading and differential movement of the top half of the sample. Soil samples are sheared horizontally under different normal loads. A plot of maximum shear stress versus normal stress is presented for each normal load. The resulting relationship of normal stress to maximum shear stress provides the shear stress parameters of cohesion intercept and angle of internal friction.

**Methods:** ASTM D 3080-72 (reapproved 1979), Method for Direct Shear Test of Soils Under Consolidated Drained Conditions.

**Limitations and Precautions:** The test is generally performed on granular soils, but it has been used for fine-grained soils. Because the direct shear test does not allow control or measurement of some important factors in the test (e.g., pore pressure, actual state of stress), experienced judgment must be used in interpreting and applying the results. Pore pressure increase or decrease during shear may occur, depending on the rate of shear and soil type.

### Triaxial Compression

**Purpose:** Triaxial compression tests are used to determine the strength of soils; these tests have an advantage in that many of the important factors that control soil strength can be simulated in the test. These factors include preloading conditions of the soil, initial stress state in the soil, drainage conditions during loading, and stress changes during soil loading. Triaxial test results are used for stability analyses of foundations, excavations, and embankments.

**Synopsis:** A cylindrical soil specimen is prepared and installed within a rubber membrane and is placed within the triaxial testing cell. A predetermined lateral or confining pressure is applied, and the sample is loaded until the maximum stress constituting failure is reached. The test may be performed at a controlled strain rate or at a controlled stress rate.

**Methods:** ASTM D 2850-82, Test Method for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression.

**Limitations and Precautions:** A thorough discussion of triaxial testing is beyond the scope of this subsection. Application of triaxial testing demands careful attention to, and clear specification of, test methods to properly simulate desired conditions; use of "standard" methods can be made only in the most general sense. These tests should be used only under the direct supervision of a geotechnical engineer.

### Vane Shear

**Purpose:** The vane shear test provides a rapid estimate of the shear strength of a cohesive soil. It is useful for approximating allowable soil pressures, safe slopes, and lateral soil pressures on buried structures. This estimate of shearing resistance may also be compared with empirical results of similar soils with regard to strength properties.

**Synopsis:** The vane shear instrument consists of a bladed vane on the end of a rod. The vane is pushed into the soil sample and rotated. The maximum torque required to turn the vane is measured and the results can be used to compute the shearing resistance of the soil. A torvane is a small vane shear instrument that can be pushed into a flat surface of a soil specimen. It gives only a general indication of the shearing resistance of cohesive soils.

**Methods:** ASTM D 2573-72 (reapproved), Test Method for Field Vane Shear Test in Cohesive Soil.

**Limitations and Precautions:** The shearing resistance obtained by the torvane is only an estimate of the actual resistance that may exist in a soil mass. Operator procedure and instrument condition may greatly affect the results of the test. The pocket torvane is useful only as a rough indicator of soil consistency. This test is applicable only to fine-grained soils.

### Moisture-Penetration Resistance

**Purpose:** Moisture-penetration tests are used to develop a correlation between penetration of a standard-size penetrometer needle and the density at a specific moisture content of a soil. The results of the test allow rapid collection of estimates of densities and moisture content for various soils used in earthworks.

**Synopsis:** The resistance of the soil to penetration is determined on each soil sample by penetration of the sample with a soil penetrometer, which consists of a spring-loaded tube with a graduated pressure scale and a needle of known length and end area. The penetration-pressure reading is divided by the area of the needle and presents values of force per unit area. The results are presented as plot of the penetration resistance values versus moisture content of the samples.

**Methods:** ASTM D 1558-84, Test Method for Moisture Content Penetration Resistance Relations of Fine-Grained Soils.

**Limitations and Precautions:** Penetration resistance of granular or extremely dry soils is difficult; the results obtained, if any, may not be applicable.

Bearing Ratio

**Purpose:** This test determines the bearing ratio of a compacted soil by comparison of the penetration load of the compacted soil with that of a standard crushed gravel material. The results of the test are used with empirical relationships in evaluating the relative strength of near surface soils to be used as roadways.

**Synopsis:** A sample is divided into at least four equal portions, the moisture content is adjusted, and the sample is compacted in accordance with ASTM D 698 or D 1557. The sample is surcharged with a predetermined weight, and a penetration piston is seated on the sample. A load is applied to the sample through the penetration piston at a specified strain rate. Load versus penetration is recorded during the test. A load-versus-penetration curve is prepared. The bearing ratios are then calculated by dividing the loads from the test by standard loads of 1,000 psi and 1,500 psi. The bearing ratio reported for the soil is normally based on 0.1 inch of penetration.

**Methods:** ASTM D 1883-73 (reapproved 1978), Test Method for Bearing Ratio of Laboratory-Compacted Soils.

**Limitations and Precautions:** The test is an empirical relationship that compares the penetration of remolded compacted soils to the penetration of uniformly crushed gravel material. Proper engineering judgment must be used in applying the results of this test.

#### 9.6.3.1.4 Deformation Tests

One-Dimensional Consolidation

**Purpose:** The one-dimensional consolidation test results are used to predict the amount and rate of settlement (or consolidation) of a soil mass subjected to sustained loads.

**Synopsis:** A soil sample is trimmed and placed in a consolidation ring that restrains it laterally. Porous stones are placed on the top and the bottom of the sample to allow drainage of pore water. The sample is then loaded, and the change in the sample height is recorded with time. Loads are applied in increments, and the test is repeated. The time-rate deformation of the sample is presented as plots of log of time or square root of time versus deformation. Plots of void ratio (or percent compression) versus log of pressure curve are prepared for use in assessing total settlement.

**Methods:** ASTM D 2435-80, Test Method for One-Dimensional Consolidation Properties of Soils.

**Limitations and Precautions:** Sample disturbance, scale differences between a laboratory sample and actual conditions, and interpretation of primary and secondary compression are areas requiring engineering judgment in application of the test results.

Swell Test

**Purpose:** The swell test is used to determine the percentage of volume change or the maximum swelling pressure of a soil as a result of changes in moisture content. The test results are used to determine the suitability of a soil for use in earthworks and to minimize the impact of swelling soils on engineering projects.

**Synopsis:** A sample is prepared and placed in a consolidation ring that provides lateral restraint. The sample is subjected to a small vertical pressure, and water is introduced to the sample; the vertical expansion with time or the force required to prevent expansion is then recorded. A percentage of volume change or swell pressure is presented as the results of the test.

**Methods:** ASTM D 4546-85, Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils.

**Limitations and Precautions:** The results of the test will yield information on soils under extreme conditions. Changes in moisture content, soil structure during sampling, sample handling, and preparation will lead to results that are only rough approximations. Proper engineering judgment must be used in applying the test results to actual problems.

### 9.6.3.1.5 Permeability Tests

Undisturbed Samples (Cohesive)

**Purpose:** Permeability tests are performed to estimate the ability of a soil to transmit water under saturated conditions. Results of the permeability test are used to estimate the quantity and flowrate of water through the soil.

**Synopsis:** The sample is trimmed, measured, weighed, placed in the triaxial cell, and back-pressure saturated. The sample can be consolidated to approximate anticipated field conditions. Flow across the sample is induced by application of differential pressure across the sample and is measured until flow reaches steady-state conditions.

**Methods:** No standard method exists at this time for performing the test. Information concerning the generally accepted test methods is found in the references.

**Limitations and Precautions:** Test methods, temperature, sample disturbance variability, and sample preparation may affect the test results.

Recompacted Samples (Cohesionless and Cohesive)

**Purpose:** This permeability test is performed to estimate the permeability of a compacted soil. Permeability is a measure of the ease with which water can move through a compacted soil. Results of the permeability test are used to estimate the quantity and flowrate of water through embankments and liners.

**Synopsis:** Laboratory determination of permeability (also termed hydraulic conductivity) can be performed as falling-head or constant-head tests. Permeameters that apply a constant head to the sample are generally used to test noncohesive or granular soils. Permeameters that apply a falling or varying head are generally used to test cohesive or fine-grained soils. Samples to be tested are prepared and generally compacted to approximate field densities in the proper type of permeameter. The flow through the sample is initiated. For the constant-head permeameters, the quantity of flow through the sample versus time is recorded. For the falling-head permeameter, the change in head or pressure across the sample and the change in volume with respect to time are recorded. Hydraulic conductivity is calculated by applying data obtained during the test to Darcy's equation.

**Methods:** ASTM D 2434-68 (reapproved 1974), Test Method for Permeability of Granular Soils (Constant Head). No standard currently exists for performing the falling-head test. Generally accepted test methods are given in the references.

**Limitations and Precautions:** Laboratory samples are extremely small when compared to conditions. Disturbance of samples occurs, methods of testing are not universally standardized, and extrapolation to field conditions may be approximate at best. Determinations of the coefficient of permeability are generally considered to be accurate only within an order of magnitude. Therefore, the quantities and the rates of flow must also be considered accurate within an order of magnitude. These factors dictate the use of proper engineering judgment in applying the results of a permeability test.

### 9.6.3.2 Rock

#### 9.6.3.2.1 Apparent Specific Gravity

**Purpose:** The apparent specific gravity of rock is determined to obtain the rock unit weight (bulk density), from which vertical and horizontal loads on subsurface installations can be estimated.

**Synopsis:** Specimens of regular shape (cylinders or blocks) can be weighed, and the volume can be determined by measurement. The apparent specific gravity is the ratio of the weight of the specimen to the weight of a volume of water having the same volume as the specimen. For irregularly shaped specimens, each may be weighed in air and again while suspended and submersed in water. A formula can be used to determine the apparent specific gravity.

**Methods:** ASTM C 127-83, Standard Test Methods for Absorption and Bulk Specific Gravity of Natural Building Stones.

**Limitations and Precautions:** Depending on the character of the rock in its natural deposits, the overall bulk density of the deposits may be less than that estimated on the basis of the specific gravity of the sample. This difference is because joints and cavities and other discontinuities reduce the overall density of the natural deposits.

#### 9.6.3.2.2 Uniaxial Compressive Strength

**Purpose:** The uniaxial compressive strength of the rock can be used as an indicator of rock quality and can be used in forming judgments about the allowable bearing pressure for foundations.

**Synopsis:** A prismatic or cylindrical sample of rock is loaded to failure in a compression-testing machine. A record of stress versus strain is made to enable determination of the elastic modulus of the rock.

**Methods:** ASTM C 170-85, Test Method for Compressive Strength of Natural Building Stone.

**Limitations and Precautions:** The number of factors that can affect the test results significantly includes flatness of the bearing surfaces, specimen size and shape, moisture content in the specimen, effect of friction between the bearing platens and the specimens, alignment of the swivel head, and rate of loading. A standardized procedure to account for most of these factors has been proposed by the U.S. Bureau of Mines. The most significant limitation of the uniaxial compressive strength test is that the strength of an individual specimen of rock in a laboratory will probably not be representative of the strength of a large mass of rock in the field. An exception may be a massive unjointed, unweathered rock deposit. Any discontinuities found in the rock mass (such as fractures, joints, and cavities) will lower the compressive strength of the rock mass.

### 9.6.3.2.3 Direct Tensile Strength

**Purpose:** The direct tensile strength of rock is useful in calculating rock stability and strength in situations where the rock is stressed in tension.

**Synopsis:** A regularly shaped specimen of rock (usually cyclindrical) is cemented to grips or loading heads that can be used to pull on the specimen without inducing undue local stress concentrations that would cause premature failure of the specimen. The specimen is then lowered in tension in a testing machine. A record of stress versus strain can be made to compute the elastic modulus in tension.

**Methods:** ASTM D 2936-84, Test Method for Direct Tensile Strength of Intact Rock Core Specimens.

**Limitations and Precautions:** The applied tensile load must be uniformly distributed over the end of the specimen. The load must be parallel to the specimen's central axis. The grips used for holding the specimen must not produce significant lateral stresses in the specimen. The end of the specimen must be perpendicular to the specimen's central axis within a very small tolerance. As with other tests on rock specimens, the laboratory properties of an individual specimen may not be representative of the properties of a rock mass. The behavior of a rock mass is primarily controlled by its imperfections, such as joints. bedding planes, fractures, and cavities, rather than by the mechanical properties of the individual particles of rock in the mass.

### 9.6.3.2.4 Splitting Tensile Strength

**Purpose:** The direct tensile strength of rock is useful primarily in calculating the permissible span of roofs above openings in rock. It may also be useful in calculating allowable slopes for excavations in rock.

**Synopsis:** A cylindrical test specimen of the rock is placed in a testing machine so that a load is applied to the sides of the cylinder along two lines 180 degrees apart. The specimen is then loaded to failure. Loading in this manner generally results in a fracture that develops on a plane through the central axis of the specimen and extends from one loading platen to the other.

**Methods:** ASTM D 3967-81, Test Method for Splitting Tensile Strength of Intact Rock Core Specimens.

**Limitations and Precautions:** Care must be taken to prevent local stress concentrations at the loading heads. The tensile strength that is determined from a splitting tensile test will generally be greater than that determined from a direct tensile test. This result occurs because the splitting tensile test forces the plane of failure to be near the center of the specimen, whereas in the direct tensile test there is a greater opportunity for the specimen to fail at the weakest plane in the specimen.

### 9.6.3.2.5 Flexural Strength (Modulus of Rupture)

**Purpose:** The flexural strength or modulus-of-rupture test provides a measure of the tensile strength of the material when loaded as a beam. This result can be used in the stability analysis of conditions involving rock flexural stresses.

**Synopsis:** A small rectangular specimen is supported on either end on knife edges and is then loaded at midpoint on the opposite side of the specimen until the specimen fails.

**Methods:** ASTM C 99-85, Test Method for Modulus of Rupture of Natural Building Stone.

**Limitations and Precautions:** A number of specimens should be tested, since this test will produce variable results even with careful specimen preparation. Tests should be made both parallel to and perpendicular to any naturally occurring planes of weakness in the rock. The tensile strength determined by the flexural test will generally be higher than that determined by the direct tensile test. The properties of the rock mass will probably be less than those computed based on individual laboratory specimens because of defects in the rock mass such as joints, bedding planes, fractures, and cavities.

#### 9.6.3.2.6 Soundness

**Purpose:** This test furnishes information that aids in judging the resistance of rock to weathering, especially as a result of freezing and thawing.

**Synopsis:** Rock specimens are repeatedly submerged in saturated solutions of sodium or magnesium sulfate and are oven dried to partially or completely dehydrate the salt-precipitated impermeable pore spaces. When the specimen is reimmersed, the rehydration of the salts creates an internal expansive force that simulates the expansion of water when freezing.

**Methods:** ASTM C 88-83, Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate.

**Limitations and Precautions:** This test is intended to give only a preliminary indication of the probable weathering resistance of the rock material. A better method for judging the weathering durability of rock material is to observe specimens that are the same material and that have been in service for a number of years.

### 9.6.3.3 Materials

#### 9.6.3.3.1 Concrete

Compressive Strength

**Purpose:** The test determines the compressive strength of cylindrical concrete specimens, such as molded cylinders or drilled cores, for conformance to specifications of concrete primarily under compressive loadings.

**Synopsis:** The test method consists of applying a compressive axial load to cylindrical concrete specimens at a rate within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

**Methods:** Refer to ASTM C 39-83b, Test Method for Compressive Strength of Cylindrical Concrete Specimens.

**Limitations and Precautions:** Special sample handling and curing procedures must be followed. Testing equipment must be in current calibration to a standard load. The test result relates more to the conformance of the concrete batch to the mix design specified than to the actual strength of concrete in place.

## Entrained Air

Entrained air in concrete improves resistance to freezing and thawing damage in hardened concrete.

**Purpose:** The test determines the air content of freshly mixed concrete for conformance to specifications.

**Synopsis:** Freshly mixed concrete is placed in a measuring bowl. A cover assembly containing an air pump, gauge, and valves is sealed to the bowl. The operation employs the principle of Boyle's law to observe the change in volume of the concrete with a change in pressure.

**Methods:** ASTM C 231-82, Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method; and ASTM C 173-78, Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method.

**Limitations and Precautions:** Calibration of equipment is essential to achieve accurate test results. Start tests within 5 minutes after obtaining the final portion of the composite sample.

## Flexural Strength

Concrete specimens are subjected to flexural or tension loadings. The test yields the flexural strength of the concrete.

**Purpose:** The flexural strength of concrete is determined by the use of a simple beam specimen of concrete with third-point loading.

**Synopsis:** A rectangular prism of hardened concrete is supported by two load-applying blocks near each end. Two load-applying blocks are located on top of the specimen at third-points. A controlled rate load is applied until failure. The modulus of rupture is calculated for the specimen.

**Methods:** ASTM C 78-84, Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading); and ASTM C 293-79, Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading) (not an alternative to C 78-84).

**Limitations and Precautions:** Special handling and curing procedures must be followed. Testing equipment must be in current calibration to a standard load.

## Specific Gravity and Absorption

**Purpose:** This test determines the specific gravity, absorption, and voids in hardened concrete. It is useful in developing data required for mass/ volume conversions for concrete, allowing conformance to specifications, and showing variability from place to place within a mass of concrete.

**Synopsis:** An oven-dried specimen of concrete is weighed in air, submerged for a period of time, weighed under saturated surface dry conditions, and then boiled for 5 hours. After cooling and reweighing surface dry, the specimen is immersed and weighed in water. The values of specific gravity, absorption, and voids are calculated from the measurements taken.

**Methods:** ASTM C 642-82, Test Method for Specific Gravity, Absorption, and Voids in Hardened Concrete.

**Limitations and Precautions:** Specimens may be pieces of cylinders, cores, or beams; specimens must be free from observable cracks, fissures, or shattered edges.

Splitting Tensile Strength

**Purpose:** When tensile strength values are not available from concrete beam specimens or are required from existing structures, compressive strength cylinders or drilled cores may be used. This test method covers the determination of the splitting tensile strength of cylindrical concrete specimens, such as molded cylinders or drilled cores.

**Synopsis:** The cylindrical specimen is positioned horizontally with a bearing plate or bar that extends the full length of the specimen and that is diametrically opposed on the top and bottom. A constant rate of load is applied until failure of the specimen. The splitting tensile strength is calculated from the maximum applied load and specimen dimensions.

**Methods:** ASTM C 496-85, Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.

**Limitations and Precautions:** Special handling and curing procedures must be followed. Testing equipment must be in current calibration to a standard load. Special alignment jigs, bearing strips, and loading apparatus are required.

#### 9.6.3.3.2 Soil-Cement

**Purpose:** Proportions of soil-cement mixtures are determined by trial batch mix designs. Strength and resistance to degradation of the mixture are evaluated by compressive strength, flexural strength, moisture-density relationship, freezing and thawing, and wetting and drying tests. Soil-cement stabilization may also be considered for solidification of some hazardous wastes.

**Synopsis:** Various amounts of cement are added to soil. The mixture is moistened to optimum water content and is compacted into specimens. The specimens are cured and removed from the molds for further curing and testing. Samples are tested at various intervals to determine compressive strength development. Other specimens are run through repetitive cycles of freezing, thawing, wetting, and drying to identify the most appropriate proportions for the soil-cement mixture.

**Methods:** ASTM D 2901-82, Test Method for Cement Content of Freshly Mixed Soil-Cement; ASTM D 806-74 (reapproved 1979), Test Method for Cement Content of Soil-Cement Mixtures; ASTM D 1632-63, (reapproved 1979), Method for Making and Curing Soil-Cement Compression and Flexural Test Specimens in the Laboratory; ASTM D 1633-84, Test Method for Compressive Strength of Molded Soil-Cement Cylinders; ASTM D 1634-63 (reapproved 1979), Test Method for Compressive Strength of Soil-Cement Using Portions of Beams Broken in Flexural (Modified Cube Method); ASTM D 1635-63 (reapproved 1979), Test Method for Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading; ASTM D 558-82, Test Methods for Moisture-Density Relations of Soil-Cement Mixtures; ASTM D 559-82, Methods for Wetting-and-Drying Tests of Compacted Soil-Cement Mixtures; and ASTM D 560-82, Methods for Freezing-and Thawing Tests of Compacted Soil-Cement Mixtures.

**Limitations and Precautions:** Not all soils are appropriate for soil-cement treatment, especially fine-grained or clayed soils. Special equipment and space are required.

### 9.6.3.3.3 Portland Cement, Blended Hydraulic Cement

**Purpose:** Several types of Portland cement are used to achieve specific properties when making concrete. Blended hydraulic cements are also available in several types to provide specific properties. It is beyond the scope of these procedures to present the physical property tests used to evaluate Portland cement and blended hydraulic cement. The reader should refer to the methods listed below.

**Methods:** ASTM C 150-85a, Specifications for Portland Cement; and ASTM C 595-86, Specification for Blended Hydraulic Cements.

### 9.6.3.3.4 Asphalt Cement

**Purpose:** Several grades of asphalt cement are available for paving and using hydraulic mixtures with aggregates. It is beyond the scope of these procedures to present the physical property tests used to evaluate asphalt cements. The reader should refer to the methods listed in ASTM Volumes 04.03, 04.04, and 04.08.

### 9.6.3.3.5 Asphalt-Stabilized Soils

**Purpose:** Emulsified or cutback asphalt may be blended with soil to increase strength and reduce permeability to water. Asphalt stabilized soils may also be considered for solidification of some hazardous waste materials.

**Synopsis:** Specimens of soil-asphalt mixtures are prepared and tested for strength, specific gravity, permeability, and stability to determine the most appropriate proportions of the soil-asphalt mixture.

**Methods:** ASTM D 4223-83, Practice for Preparation of Test Specimens of Asphalt-Stabilized Soils.

**Limitations and Precautions:** Special equipment and space are required. Special handling of asphalt materials and associated solvents is necessary.

### 9.6.3.3.6 Geotextiles

Fabric Weight

**Purpose:** The fabric weight is directly related to the fabric tensile strength and, therefore, provides an index of strength.

**Synopsis:** The fabric weight test is conducted by cutting a sample of fabric and measuring its dimensions and weight. The fabric weight is calculated as the total weight of the sample divided by its area.

**Methods:** ASTM D 3773-84, Test Method for Length of Woven Fabric, 07.01; ASTM D 3774-84, Test Method for Width of Woven Fabric, 07.01; ASTM D 3775-85, Test Method for Fabric Count of Woven Fabric, 07.01; and ASTM D 3776-85, Test Methods for Mass per Unit Area (Weight) of Woven Fabric, 07.01.

**Limitations and Precautions:** Potential error is reduced by using as large a sample as possible.

### Fabric Thickness

**Purpose:** The thickness of a geotextile is an index to its ability to absorb impacts and transport water (for constant density).

**Synopsis:** A sample of fabric is placed on an anvil, and gradual pressure is applied by means of a fixed-weighted, mechanical foot. The thickness (distance between the anvil and foot) is measured.

**Methods:** ASTM D 1777-64 (reapproved 1975), Method for Measuring Thickness of Textile Materials, 07.01.

**Limitations and Precautions:** Different methods of finishing geotextiles (e.g., spun-bonding, needle punching, heat bonding) may alter the deformation properties of the material, thus affecting the thickness measurement.

### Grab Tensile Strength and Elongation

**Purpose:** The grab tensile test is the most commonly used strength and elongation index for woven fabrics. The test provides a good indication of strength and deformation during installation.

**Synopsis:** The grab tensile test involves using a specified size sample of fabric loaded in tension between two clamps. The clamps are moved apart at a constant rate until failure of the fabric is achieved. The load at failure is the ultimate grab tensile strength; the deformation at failure is the elongation.

**Methods:** ASTM D 1682-64 (1975), Test Methods for Breaking Load and Elongation of Textile Fabrics, 07.01.

**Limitations and Precautions:** Because fabrics are often subjected to multidirectional stresses in actual use, this method may not provide a good indication of the strength or deformations after placement.

### Creep

**Purpose:** Creep tests of fabrics are used to assess potential loss of a reinforcing capability because of time-dependent fabric deformation.

**Synopsis:** Creep tests are conducted by hanging a constant weight on a strip of fabric and measuring the deformation (elongation) of the fabric over a period of time.

**Methods:** Standard methods are not currently available. Creep tests must be carefully designed on a case-by-case basis considering the specific loading conditions anticipated. Proprietary methods developed by manufacturers are available.

**Limitations and Precautions:** Creep tests that apply loads and measure deformation in only one direction have limited application to actual field conditions.

### Abrasion Resistance

**Purpose:** Abrasion tests are used to assess the resistance of a fabric to wear by friction. Abrasion may be a concern in applications where relative movement occurs frequently (perhaps cyclically) between the fabric and adjacent soils or materials (e.g., under riprap at shoreline or under heavily loaded road or rail beds).

**Synopsis:** Not applicable.

**Methods:** No standards are currently available. The reader should refer to manufacturers for information and methods.

**Limitations and Precautions:** Current test methods may not be relevant to most hazardous waste applications.

Puncture Resistance

**Purpose:** The puncture resistance is important in assessing the ability of a fabric to resist abuse during installation (e.g., compaction of gravels on top of or around a fabric).

**Synopsis:** A sample of fabric is placed in a ring clamp, and the fabric is penetrated by a hemispherically tipped steel cylinder advanced at a specified rate. The load required to penetrate the fabric is the puncture strength.

**Methods:** ASTM D 751-79, Method of Testing Coated Fabrics, 09.02.

**Limitations and Precautions:** The reader should refer to the standard method.

Mullen Burst Strength

**Purpose:** The Mullen Burst Test is used to assess fabric strength when fabric is subjected to multidimensional loads that may be more representative of actual field loads after placement.

**Synopsis:** A sample of fabric is placed in a circular clamp and loaded hydrostatically at a constant rate through an inflatable membrane. The pressure required to rupture the fabric is the burst point.

**Methods:** ASTM D 3786-80a, Test Method for Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics: Diaphragm Bursting Strength Tester Method, 07.01.

**Limitations and Precautions:** The test results must be carefully interpreted because of the small sample size and potential edge effects of the clamp.

Trapezoid Tearing Strength

**Purpose:** The trapezoid tearing strength test is useful in assessing the tendency of a fabric to continue to tear when tearing is initiated.

**Synopsis:** A sample of the fabric is marked with an outline of a trapezoid, and the nonparallel sides are clamped in parallel jaws of the testing machine. The jaws are separated at a constant rate, and a continuously increasing load is applied to continue tearing the sample. The load versus deformation curve is recorded, and the maximum (peak) load determined is the tearing strength.

**Methods:** ASTM D 1117-80, Methods of Testing Nonwoven Fabrics, 07.01.

**Limitations and Precautions:** The reader should refer to the standard method.

Equivalent Opening Size (EOS)

**Purpose:** The equivalent opening size test compares opening size in fabrics to U.S. standard sieve sizes to help evaluate the performance of filter fabric.

**Synopsis:** A sample of filter fabric is attached to a U.S. standard sieve with openings larger than the largest beads to be used. The beads are placed in the sieve and shaken for a fixed period. The size of beads, of which 5 percent or less (by weight) pass through the fabric, is determined by sieving. The EOS of the fabric is the U.S. standard sieve number which retains this fraction of the glass beads.

**Methods:** U.S. Army Corps of Engineers' Guidelines.

**Limitations and Precautions:** The reader should refer to the standard method.

Planar Flow

**Purpose:** Planar flow test results are used to help evaluate the capacity of a fabric to transmit fluid in the plane of the fabric.

**Synopsis:** Circular fabric samples are placed between flat plates and compressed at a set pressure. Fluid flow is induced under constant hydraulic head from the middle of the sample to the edges. The transmissibility is used as a measure of flow capacity because it includes both permeability and thickness.

**Methods:** No standard methods are available.

**Limitations and Precautions:** The reader should refer to the manufacturer.

Normal Permeability

**Purpose:** Normal permeability test results are used to evaluate the capacity of a fabric to transmit fluid perpendicular to the plane of the fabric. The test helps evaluate infiltration and evaporation rates across fabrics and is important in evaluating fabrics for drainage applications.

**Synopsis:** Normal permeability tests can be conducted by clamping a sample of fabric across the base of cylinder, filling the cylinder with fluid, and measuring the rate of fluid flow through the sample as in a falling-head test.

**Methods:** No standard methods are available.

**Limitations and Precautions:** The reader should refer to the manufacturer.

Coefficient of Friction (Soil to Fabric)

**Purpose:** Determining the coefficient of friction between a fabric and soil is essential in evaluating the ability of the fabric to provide lateral reinforcement of the soil. The coefficient of friction provides a measure of the ability to transfer stresses to the fabric, which may affect the thickness of cover required to prevent shifting of the fabric.

**Synopsis:** Samples of fabric are placed on a horizontal surface, and a sample of soil is placed at one end. The end is raised and the angle of the incline at which the soil starts to slide is measured. The coefficient of friction is the trigonometric tangent of the angle of inclination at incipient sliding.

**Methods:** No standard methods are available.

**Limitations and Precautions:** The reader should refer to the manufacturer.

Coefficient of Friction (Fabric to Fabric)

**Purpose:** The coefficient of friction between two fabrics is essential for evaluating the required overlap needed to keep fabrics in place (unbonded seams) and to evaluate the ability of layered fabric systems to transmit lateral stresses or to resist sliding.

**Synopsis:** Samples of fabric are overlapped and clamped together at fixed pressures. The fabrics are pulled at a constant rate to cause differential movement between the fabric samples, and the force is measured. The first peak load corresponds to the static friction load.

**Methods:** No standard methods are available.

**Limitations and Precautions:** The reader should refer to the manufacturer.

Alkali or Acid Stability

**Purpose:** Alkali or acid stability tests are used to assess potential fabric deterioration caused by exposure to or contact with acidic or basic solutions. Potential deterioration may affect the performance and effective service life of fabrics in drains, liners, and covers.

**Synopsis:** Fabric samples are attached to frames and placed in alkali or acid baths at constant pH. Samples are periodically removed from the baths, dried, and tested (e.g., grab tensile test). The changes in tensile strength with prolonged bath exposure provide information on the rates of deterioration.

**Methods:** No standards currently exist.

**Limitations and Precautions:** Within practical limits, the duration of bath exposure may not be representative of field conditions. Extrapolations to estimate actual field service life may be questionable.

Thermal Shrinkage

**Purpose:** The results of thermal shrinkage tests can be used to evaluate potential deformations of fabric in hot environment applications (e.g., contact with hot asphalts or exothermic chemical reactions).

**Synopsis:** Samples of fabric are placed in ovens at various temperatures and are periodically measured for unrestrained deformation.

**Methods:** The reader should see ASTM methods for width and length measurements that are listed earlier in this compendium under "Fabric Weight."

**Limitations and Precautions:** Because measurements are made on unrestrained fabric samples, the test may not be representative of field conditions. Since thermally induced stresses are not measured, the results cannot be used to assess these potential effects.

Ultraviolet Stability

**Purpose:** The results of ultraviolet stability tests allow assessment of potential deterioration of fabrics that are subjected to sunlight. These assessments can be used to evaluate changes in effectiveness and to predict the service life of the fabrics.

**Synopsis:** Fabric samples are exposed to ultraviolet light (either artificial or natural sunlight) and are periodically tested (e.g., grab tensile test). The changes in tensile strength indicate the rate of fabric deterioration.

**Methods:** The reader should see the ASTM method listed earlier in this compendium under "Grab Tensile Strength and Elongation Tests" in this subsection.

**Limitations and Precautions:** Practical limits on the duration of testing may not represent actual field conditions. Extrapolations of test results to assess long-term effects may be questionable.

### 9.6.3.3.7 Geomembranes

Polymeric flexible membranes are available supported (reinforced) or unsupported (nonreinforced). The general types of materials used are elastomeric (rubber), thermoplastic, semicrystalline, or alloys of the various polymers. The physical test specifications to be used depend on the polymer and whether it is supported or not. Many of the test specifications used by manufacturers and listed in National Sanitation Foundation Standard 54 were developed for other purposes and are being used since specifications for specific geomembrane materials and properties are unavailable at this time.

Thickness

**Purpose:** The thickness of a geomembrane is proportional to the strength and elongation properties.

**Synopsis:** Three methods for measurement of thickness are presented below. The method selected will depend on the specification for the particular geomembrane.

**Methods:** ASTM D 1593-8, Specification for Nonrigid Vinyl Chloride Plastic Sheeting; ASTM D 751-79, Method of Testing Coasted Fabrics; and ASTM D 412-83, Test Methods for Rubber Properties in Tension.

**Limitations and Precautions:** A special apparatus is required to make measurements.

Specific Gravity

**Purpose:** The specific gravity measurement of a geomembrane is useful in determining the unit weight of materials.

**Synopsis:** The test method covers the determination of specific gravity and density of solid plastics by displacement of liquid and the determination of change in weight.

**Methods:** ASTM D 792-66, Test Methods for Specific Gravity and Density of Plastics by Displacement.

**Limitations and Precautions:** Special equipment may be required.

## Tensile Strength

**Purpose:** The tensile strength of a geomembrane is an important design parameter related to the ability to withstand the movement of the geomembrane into place, to support itself on slopes, and to withstand operational stress.

**Synopsis:** There are four methods for determining the tensile strength of geomembranes. The appropriate method will depend on the type of polymeric geomembrane being tested.

**Methods:** ASTM D 882-83, Test Methods for Tensile Properties of Thin Plastic Sheeting; ASTM D 751-79, Method for Testing Coated Fabric; ASTM D 412-83, Test Method for Rubber Properties in Tension; and ASTM D 638-84, Test Method for Tensile Properties of Plastics.

**Limitations and Precautions:** The reader should refer to test methods listed above.

## Elongation

**Purpose:** The elongation of a geomembrane is an extension produced by tensile stress. Elongation provides some measure of the material's ability to accommodate minor deformation.

**Synopsis:** There are four methods for determining the elongation of geomembranes. The measurement is usually an adjunct to the tensile strength test. The appropriate method will depend on the polymeric geomembrane being tested.

**Methods:** The reader should see the methods that are listed earlier in this compendium under "Tensile Strength."

**Limitations and Precautions:** Refer to the test methods listed above.

## Tear Resistance

**Purpose:** The tear resistance is a measure of the strength of the geomembrane at a point of stress. The tear resistance of a geomembrane is the stress required to propagate a cut or slit at the edge of a membrane specimen under strain.

**Synopsis:** There are three methods for determining the tear resistance of geomembranes. The appropriate method will depend on the polymeric geomembrane being tested.

**Methods:** ASTM D 1004-66(1981), Test Method for Initial Tear Resistance of Plastic Film and Sheeting; ASTM D 751-79, Method of Testing Coated Fabrics; and ASTM D 624-86, Test Method for Rubber Property.

**Limitations and Precautions:** The reader should refer to the test methods listed above.

## Dimensional Stability

**Purpose:** The measurement of linear dimensional changes of geomembranes at elevated temperature suggests the behavior of the materials in the field when exposed to solar heating during placement.

**Synopsis:** The reader should refer to National Sanitation Foundation Standard 54 for Flexible Membrane Liners, 1983, for details of the test. This method is proposed for all geomembranes listed in Standard 54.

**Methods:** ASTM D 1204-84, Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature.

**Limitations and Precautions:** The reader should refer to the test method listed above.

Bonded Seam Strength

**Purpose:** The seam strength is the single most important concern for lining integrity, and it applies to both factory-made and field-made seams.

**Synopsis:** A tensile strength test is performed on a specimen prepared to have a seam under shearing stress. The specimen is tested to failure to determine the maximum stress. The specimen is examined to determine if the failure was within the seam or in the parent material.

**Methods:** ASTM D 3083-76(1980), Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining; and ASTM D 751-79, Testing Coated Fabrics.

**Limitations and Precautions:** Specimens require special handling and curing before testing. The testing machine must be currently calibrated to a standard. A special testing apparatus is required.

Peel Adhesion

**Purpose:** The tensile strength of geomembrane seams by 180 degree peel is the definitive test of the bond strength.

**Synopsis:** The tensile stress is applied to material on adjacent sides of the seam to create a 180 degree strain on the bonded seam. The sample is tested to failure, and the failure location is noted as being in the seam or in the parent material.

**Methods:** ASTM D 413-82, Test Methods for Rubber Property-Adhesion to Flexible Substrate.

**Limitations and Precautions:** Specimens require special handling and curing prior to testing. The testing machine must be currently calibrated to a standard. A special testing apparatus is required.

## 9.6.4 Chemical Properties of Soil and Rock

### 9.6.4.1 Waste Evaluation Procedures

Section 262.11 of the Resource Conservation and Recovery Act (RCRA) regulations requires that a generator of a "solid waste"—i.e., any garbage, refuse, sludge, or other waste that is not excluded under Section 261.4(a)—must do the following:

1. Determine if the waste is excluded.

2. If the waste is not excluded, determine whether the waste is listed as a hazardous waste.

3. If the waste is not excluded and not listed, then evaluate the waste in terms of the four hazardous characteristics—ignitability, corrosivity, reactivity, and extraction procedure toxicity—unless the generator can properly evaluate the waste based upon previous experiencd (e.g., corrosivity testing may not be required if the generator has a long history of running the waste through steel pipes without any evidence of corrosion).

### 9.6.4.1.1 Ignitability (RCRA Requirement)

**Purpose:** The ignitability test identifies wastes that either present fire hazards under routine storage, disposal, and transportation, or are capable of severely exacerbating a fire once it has started.

**Synopsis:** The following two methods are approved by the EPA:

1. The Pensky-Martens closed-cup method uses the closed-cup tester to determine the flash point of fuel oils, lubrication oils, suspension solids, liquids that tend to form a surface film under test conditions, and other liquids.

   The sample is heated at a slow, constant rate and is continually stirred. A small flame is directed into the cup at regular intervals while simultaneously interrupting the stirring. The flash point is the lowest temperature at which application of the test flame ignited the vapor above the sample.

2. The Setaflash closed-cup method uses the Setaflash Closed Tester to determine the flash point of paints, enamels, lacquers, varnishes, and related products and their components that have flash points between 0°C and 110°C (32°F and 230°F) and viscosity lower than 150 stokes at 25°C. Tests at higher or lower temperatures are possible.

   The procedures may be used to determine whether a material will or will not flash at a specified temperature, or to determine the finite temperature at which a material will flash.

**Methods:** EPA SW-846, Test Methods for Evaluating Solid Waste, Methods 1010 and 1020.

**Limitations and Precautions:** Ambient pressure, sample homogeneity, drafts, and operator bias can affect flash point values. Quality control data as specified under Method 1010 and Method 1020 should be available for review.

### 9.6.4.1.2 Corrosivity (RCRA Requirement)

**Purpose:** The corrosivity test identifies wastes that might pose a hazard to human health or the environment because of their ability to do the following:

- Mobilize toxic metals if discharged into a landfill environment
- Corrode handling, storage, transportation, and management equipment
- Destroy human or animal tissue in the event of inadvertent contact

To identify such potentially hazardous materials, EPA has selected two properties on which to base the definition of a corrosive waste. These properties are pH and corrosivity toward SAE Type 1020 steel. The procedures for pH are described in this Subsection 9.6.4.2.5. Corrosivity toward steel is used for both aqueous and nonaqueous liquid wastes. This test exposes coupons of SAE Type 1020 steel to the liquid waste to be evaluated and, by measuring the degree to which the coupon has dissolved, determines the corrosivity of the waste.

**Methods:** EPA SW-846, Test Methods for Evaluating Solid Waste, Method 1110. Corrosivity of Steel.

**Limitations and Precautions:** In laboratory tests, such as Method 1110, corrosion of duplicate coupons is usually reproducible to within 10 percent. However, large differences in corrosion rates may occasionally occur under conditions in which the metal surfaces have become passivated. Therefore, at least duplicate determinations of the corrosion rate should be made. Exact requirements are to be included in the QA plan and specified in the laboratory.

### 9.6.4.1.3 Reactivity (RCRA Requirement)

**Purpose:** The reactivity test identifies wastes that, because of their extreme instability and their tendency to react violently or explode, pose a problem at all stages of the waste management process.

**Synopsis:** The EPA gives a descriptive definition of reactivity, because the available tests for measuring the variegated class of effects embraced by the reactivity definition suffer from a number of deficiencies.

**Methods:** See regulatory definition in EPA SW-846, Test Methods for Evaluating Solid Waste, Section 2.1.3 – Reactivity.

**Limitations and Precautions:** The reader should refer to Subsection 2.1.3 in EPA SW-846.

### 9.6.4.1.4 Extraction Procedure (EP) Toxicity Test Method and Structural Integrity Test

**Purpose:** This test is used to simulate the leaching a waste may undergo if it is disposed of in a landfill. The test is applicable to liquid, solid, and multiphasic samples.

**Synopsis:** If a representative sample of waste contains more than 0.5 percent solids, the solid phase of the sample is extracted with deionized water that is maintained at a pH of 5 ±0.2 using acetic acid. The extract is analyzed for the specified priority pollutants (As, Ba, Cd, Cr, Pb, Hg, Se, Ag, endrin, lindane, methoxychlor, toxaphene, 2,4 D, 2,4,5-TP Silvex]) by the appropriate tests as described under organic and inorganic priority pollutant analyses. Wastes that contain less than 0.5 percent are not subjected to extraction, but they are directly analyzed and evaluated in a manner identical to that for extracts.

**Methods:** EPA SW-846, Test Methods for Evaluating Solid Waste, Method 1310.

**Limitations and Precautions:** Potential interferences that may be encountered during analyses pertain to the individual analytical methods.

#### 9.6.4.1.5 Mobility

**Purpose:** This test is used to determine the mobility of various components in a waste to evaluat contaminant transport.

**Synopsis:** A multiple extraction procedure currently is being developed by the EPA. (Method 1410) Although these procedures are used to evaluate a waste, they are not to be confused with a hazardous characteristic as defined by the RCRA regulations.

**Methods:** EPA SW-846, Test Methods for Evaluating Solid Waste, Method 1410.

**Limitations and Precautions:** The reader should see the test method.

#### 9.6.4.1.6 Acid-Base Potential (Potential Acidity With Peroxide, Neutralization Potential, Mine Spoil Potentials)

**Purpose:** Within impounded mine tailings, the potential for in situ acid formation may exist whenever pyritic sulfide is present in the waste material. If acid were to be formed by the oxidation of pyritic sulfur, the acid theoretically could dissolve and mobilize transition metals. The possibility that acid formation will occur is evaluated by measuring the acid-base potential.

**Synopsis:** Determination of the acid-base potential is the result of two independent analyses: one is an acidometric measure of the base equivalent (as calcium carbonate) of the tailings solids, and the other is a measure of the hydrogen peroxide-oxidizable sulfur that could produce sulfuric acid. The acid-base potential is the base content minus the acid content.

**Methods:** Report No. EPA-670/2-74-070, Mine Spoil Potentials for Soil and Water Quality.

**Limitations and Precautions:** The reader should see the test method.

### 9.6.4.2 Pollutant Analysis

#### 9.6.4.2.1 Organics

**Purpose:** Organics tests are used to identify and quantify the organic contaminants of the soil.

**Synopsis** The EPA has a list of organic priority pollutants for which well-defined analytical and quality control procedures have been developed. These pollutants are classified in four groups based on the extraction procedures employed before analysis: volatiles, acid extractables, base or neutral extractables, and pesticides. The major analytical procedures employed are gas chromatography and mass spectroscope. For organics other than the priority pollutants, procedures need to be obtained from literature. Appropriate descriptions should be presented to the laboratory on a special analytical services (SAS) form.

**Methods:** EPA SW-846, Test Methods for Evaluating Solid Waste, Methods 8010-8310, 3510-3550.

**Limitations and Precautions** The reader should see the test methods and the literature.

### 9.6.4.2.2 Metals

**Purpose:** Metals tests are used to identify and quantify the metal contaminants in the soil.

**Synopsis:** The EPA has a list of metal priority pollutants for which well-defined analytical and quality control procedures have been developed. In analysis requests, distinctions need to be made in total metal or extractable metal analysis. The soil is digested with a strong acid to dissolve all metals in the first, whereas an appropriate extraction method is employed in the second. The analysis methods are mainly atomic absorption and inductively coupled plasma emission. For metals that are not on the priority pollutant list, procedures need to be obtained from literature and appropriate descriptions given on the SAS form.

**Methods** EPA SW-846, Test Methods for Evaluating Solid Waste, Methods 7040-7951, 3010-3060.

**Limitations and Precautions:** The reader should see the test methods and the literature.

### 9.6.4.2.3 Total and Amenable Cyanide

**Purpose:** This test is used to determine the concentration of inorganic cyanide. The method detects inorganic cyanides that are present as either simple soluble salts or complex radicals. The test is used to determine values for both total cyanide and cyanide amenable to chlorination. It does not determine the "reactive" cyanide content of wastes containing iron-cyanide complexes.

**Synopsis:** The waste is divided into two parts. One is chlorinated to destroy susceptible complexes. Each part is distilled to remove interferences and is analyzed for cyanide. The fraction amenable to chlorination is determined by the difference in values.

During the distillation, cyanide is converted to hydrogen cyanide vapor, which is trapped in a scrubber containing sodium hydroxide solution. This solution is titrate with standard silver nitrate.

**Methods:** EPA SW-846, Test Methods for Evaluating Solid Waste, Method 9010.

**Limitations and Precautions:** Sulfides interfere with the titration, but they can be precipitated with cadmium. Fatty acids form soaps under alkaline titration conditions and interfere. The fatty acids can be extracted with a suitable solvent. Oxidizing agents can decompose the cyanide; the oxidizing agents can be treated with ascorbic acid. Thiocyanate presence will interfere by distilling over in the procedure. This situation can be prevented by adding magnesium chloride. Aldehydes and ketones can convert cyanide to cyanohydrin under the acid distillation conditions.

### 9.6.4.2.4 Total Organic Halides (TOX)

**Purpose:** This test is used to determine the total organic halides (TOX) as $Cl^-$ extract.

**Synopsis:** A sample of water that has been protected against the loss of volatiles by the elimination of headspace in the sampling container is passed through a column containing activated carbon. The column is washed to remove any trapped inorganic halides and is analyzed to convert the adsorbed organohalides to a titratable species that can be measured by a microcoulometric detector.

**Methods:** The reader should see the test methods. EPA SW-946, Test Methods for Evaluating Solid Waste, Method 9020, Total Organic Halides (TOX).

**Limitations and Precautions:** All samples must be run in duplicate. Under conditions of duplicate analysis, the reliable limit of sensitivity is 5 μl per liter.

The method detects all organic halides containing chlorine, bromine, and iodine that are adsorbed by granular-activated carbon under conditions of the method. Fluorine species are not determined by this method.

The method is applicable to samples whose inorganic-halide concentration does not exceed the organic-halide concentration, by more than 20,000 times.

#### 9.6.4.2.5 pH

**Purpose:** This test is used to measure the pH of the soil.

**Synopsis:** The soil is stirred with water and, after equilibration, the pH of the supernatant solution is measured with a glass electrode pH meter.

**Methods:** The EPA is currently developing a method, EPA SW-846, Test Methods for Evaluating Solid Waste, Method 9045.

**Limitations and Precautions:** The measured pH value may shift slightly with each change in the soil-to-water ratio used in the preparation of the soil samples, and seasonal fluctuations in pH may also be anticipated.

#### 9.6.4.2.6 Lime Requirement

**Purpose:** This test is used to determine the pH of acidic soils for estimating the amounts of lime needed to neutralize the soil.

**Synopsis:** The dried soil is mixed with a buffer solution and allowed to equilibrate, and the pH is measured with glass electrodes and a pH meter. The amount of lime needed can be estimated from experimental lime versus pH correlation curves specific to the region.

**Methods:** Methods of Soil Analysis Used in the Soil Testing Laboratory at Oregon State University, Special Report 321, Agricultural Experiment Station, Oregon State University, Corvallis, revised September 1978.

**Limitations and Precautions:** Electrodes should be rinsed very well between samples to eliminate a constant increase in the pH measured, because of electrode contamination.

### 9.6.4.3 Other Tests

#### 9.6.4.3.1 Cation Exchange Capacity

**Purpose:** This test is used to determine the exchangeable cation content of the soil. Many of the assimilative capacity determinations for constituents in industrial waste are based on cation exchange capacity measurement.

**Synopsis:** Determination of soil cation exchange capacity involves removal of all exchangeable cations by leaching the soil with an excess of neutral ammonium acetate solution and saturating the exchange material with ammonium. This procedure is followed by leaching with $Na_4Cl$. The soil is then washed with isopropyl alcohol until all chloride is removed. The ammonium adsorbed on the exchange complex is displaced by treating the soil with acidified NaCl. The displaced solution is distilled and then titrated to calculate the cation exchange capacity.

**Methods:** Methods of Soil Analysis Used in the Soil Testing Laboratory at Oregon State University, Special Report 321, Agricultural Experiment Station, Oregon State University, Corvallis, revised September 1978.

The EPA is developing a cation exchange capacity method entitled Test Methods for Evaluating Solid Waste, SW-846, Methods 9080, 9081. This method includes the ammonium acetate and the sodium acetate methods.

### 9.6.4.3.2 Extractable Cations: $K^+$, $Na^+$, $Ca^{++}$, $Mg^{++}$

**Purpose:** Extractable cation content of the soil, along with extractable hydrogen, is used to estimate the cation exchange capacity and the percentage of base saturation required for soil taxonomy.

**Synopsis:** The ions are extracted from the soil with a neutral ammonium acetate solution. The quantities of the individual ions in the solution are then determined by atomic absorption.

**Methods:** Methods of Soil Analysis Used in the Soil Testing Laboratory at Oregon State University, Special Report 321, Agricultural Experiment Station, Oregon State University, Corvallis, Method 17, revised September 1978.

**Limitations and Precautions:** The four cations are determined on the same soil extract but with different dilutions. The single-extraction technique for cations in noncalcerous soil gives values that are equivalent to at least 35 percent of the values obtained by multiple extraction. For samples that contain carbonates of $Ca^{++}$ or $Mg^{++}$, the multiple extraction with ammonium acetate may dissolve these carbonates and give higher values for $Ca^{++}$ and $Mg^{++}$ than are obtained with a single extraction. For routine testing, there is usually no interest in determining the extractable $Ca^{++}$ and $Mg^{++}$ in alkaline samples that contain free lime.

### 9.6.4.3.3 Exchangeable Hydrogen

**Purpose:** To determine the amount of acidic hydrogen that can be removed from the soil by a buffer solution. The extractable hydrogen content, along with the extractable cations, is used to estimate the cation exchange capacity, as well as the percentage of base saturation required for soil taxonomy.

**Synopsis:** The soil is mixed with a buffer solution and kept for 30 minutes while being shaken to dissolve the acidic hydrogens. The soil is then filtered. This process is repeated two more times; then the filtrate is titrated to determine the acid content.

**Methods:** Methods of Soil Analysis Used in the Soil Testing Laboratory at Oregon State University, Special Report 321, Agricultural Experiment Station, Oregon State University, Corvallis, revised September 1978.

**Limitations and Precautions:** The reader should see the test method.

### 9.6.4.3.4 Total Soluble Salts – Electrical Conductivity

**Purpose:** This test is used to measure the electrical conductivity of the soil extract as an indication of its ionic content (soluble salts).

**Synopsis:** Water is added to the soil to prepare a saturated soil paste. This paste is then filtered, and the conductivity of the filtrate is measured.

**Methods:** Methods of Soil Analysis Used in the Soil Testing Laboratory at Oregon State University, Special Report 321, Method 1, revised September 1978.

**Limitations and Precautions:** The reader should see the literature.

### 9.6.4.3.5 Carbon, Total Organic and Inorganic

**Purpose:** This test is used to determine the total organic carbon and/or the total inorganic carbon content of the soil. Carbon may exist in sediment and water samples as either inorganic or organic compounds. Inorganic carbon is present as carbonates and bicarbonates and possibly as free carbon dioxide. Specific types of organic carbon compounds are nonvolatile organic compounds (sugars), volatile organic compounds (mercaptans), partially volatile compounds (oils), and particulate carbonaceous materials (cellulose).

**Synopsis:** The basis of the method is the catalytic or chemical oxidation of carbon in carbon-containing compounds to carbon dioxide, followed by the quantification of the carbon dioxide produced. Alternately, the carbon may be reduced to methane and appropriately quantified. It then follows that the distinction between inorganic carbon and organic carbon is the method of sample pretreatment. There are presently two procedures for defining this separation. One method is based on sample treatment with a strong acid. Analysis of an untreated sample is a measure of total carbon, while analysis of the acid-treated fraction is a measure of organic carbon. Inorganic carbon is calculated by subtraction. The second method of separation is based on differential thermal combustion with organic compounds being converted to carbon dioxide at 500°C to 650°C, and inorganic carbon being converted to carbon dioxide at 950°C to 1,300°C.

**Methods:** Procedures for Handling and Chemical Analysis of Sediment and Water Samples, Russell H. Plumb, U.S. EPA and Army Corps of Engineers' Technical Committee on Criteria for Dredged and Fill Material, Contract EPA-4805572010.

### 9.6.4.3.6 Sulfides

**Purpose:** This test is used to measure the concentration of total and dissolved sulfides.

**Synopsis:** Excess iodine is added to a sample, which may or may not have been treated with zinc acetate, to produce zinc sulfide. The iodine oxidizes the sulfide to sulfur under acidic conditions. The excess iodine is back-titrated with sodium thiosulfate or phenylarsine oxide.

**Methods:** EPA SW-846, Test Methods for Evaluating Solid Waste, Method 9030; EPA Method 376(1979).

**Limitations and Precautions:** The method does not measure acid insoluble sulfides; copper sulfide is the only common acid-insoluble sulfide.

The method is suitable for measuring sulfide in concentrations above 1 mg per liter. Reduced sulfur compounds that decompose in acid, such as sulfite, thiosulfate, and hydrosulfite, may yield erratic results. Also, volatile iodine-consuming substances will give high results. Samples must be taken with a minimum of aeration to avoid volatilization of sulfides and reaction with oxygen that may convert sulfide to unmeasurable forms. If the sample is not preserved with zinc acetate, analysis must start immediately.

### 9.6.4.3.7 Total Nitrogen

**Purpose:** This test is used to determine the total nitrogen content of the soil.

**Synopsis:** In the micro-Kjeldahl method, the nitrogen in different forms is converted to the ammonium ion by digestion in sulfuric acid. The digest is distilled, and the distillate is titrated for the ammonium content from which the nitrogen content can be calculated.

**Methods:** Methods of Soil Analysis used in the Soil Testing Laboratory at Oregon State University, Special Report 321, Agricultural Experiment Station, Oregon State University, Corvallis, Method 3, revised September 1978.

### 9.6.4.3.8 Extractable Phosphorus

**Purpose:** This test is used to determine the amount of phosphorus that can be extracted with a sodium bicarbonate solution from the soil.

**Synopsis:** The sodium bicarbonate extract of the soil is treated with a complexing agent; the phosphorus complex is determined colorimetrically.

**Methods:** Methods of Soil Analysis Used in the Soil Testing Laboratory at Oregon State University, Special Report 321, Agricultural Experiment Station, Oregon State University, Corvallis, Method 15, revised September 1978.

**Limitations and Precautions:** The pH of the $NaHCO_3$ solution increases over time when exposed to the atmosphere. When the pH of the extractant exceeds 8.5, a notable increase in extractable soil is anticipated. A thin layer of mineral oil that is spread over the surface of the extracting solution will effectively decrease the rate at which the pH will change. Chemical reactions that tend to decrease the activity or concentration of soluble Ca, Al, and Fe will allow for a potential increase in soluble phosphate. The amount extracted is also dependent on the shaker time and temperature.

### 9.6.4.3.9 Total Phosphorus

**Purpose:** This test is used to determine the total phosphorus content of the soil after digestion.

**Synopsis:** Numerous methods are available for the digestion of sediment samples to be analyzed for phosphate. Most procedures consist of strong acid digestion or treatment with an oxidizing agent and a strong acid. A common feature of the digestion procedures is that the sample treatments are designed to convert all the phosphate compounds to orthophosphate. The orthophosphate is then quantified colorimetrically.

**Methods:** Procedures for Handling and Chemical Analysis of Sediment and Water Samples, Russell H. Plumb, U.S. EPA and Army Corps of Engineers' Technical Committee on Criteria for Dredged and Fill Material, Contract EPA-4805572010.

**Limitations and Precautions:** The reader should see the test method.

9.6.4.3.10 Mineralogy

**Purpose:** This test is used to determine the mineral characteristics of soil.

**Synopsis:** The most widely used techniques in mineral identification and composition determination are X-ray diffraction and optical techniques; the underlying principles are beyond the scope of this compendium. References are given in Subsection 9.8.

**Methods:** Ford, W. E. *Dana's Textbook of Mineralogy, Optical Techniques*. 4th ed. New York: John Wiley and Sons. 1966.

Hurlburt, C. S., Jr. *Manual of Mineralogy*, 19th ed. New York: John Wiley and Sons. 1977.

"X-Ray Diffraction Techniques for Mineral Identification and Mineralogical Composition," *Methods of Soil Analysis, Agronomy Monograph* No. 9, Part 1, American Society of Agronomy, 1965. (The second edition of this reference is soon to be published.) This reference provides qualitative and semiquantitative soil mineralogical analyses.

**Limitations and Precautions:** The reader should see the methods.

## 9.6.5 Compatibility Testing

Materials considered for hazardous waste applications should be analyzed for compatibility with the wastes. The analyses should determine the changes in material properties caused by contact or exposure to wastes. Materials of concern for compatibility may include natural materials (e.g., soils and rock) and synthetic materials (e.g., construction materials).

Although analytical methods are being developed, few standards for compatibility testing exist at present. Decision-makers must use their judgment and experience in evaluating the need for, and use of, compatibility test data. Those laboratories conducting the testing must be appropriately staffed and equipped. The test method must clearly document the test scope, limitations, and materials used, and provide quantification of the degree of alteration and projected useful life of the material.

In general, compatibility testing involves rational use of both chemical tests and tests of physical properties (see Subsections 9.6.3 and 9.6.4) to assess the effects of wastes on the materials. Chemical analyses may be used to determine the types and concentrations of wastes to which the material is subjected. The aggressive substance in a hazardous waste may be of low total concentration, but the substance may accumulate in a particular phase or level in the waste. Under such conditions, the concentration level may be high enough to act aggressively. Physical tests provide the basis for measuring resultant changes.

The following discussions are not intended to be all-encompassing, but they should heighten general awareness about potential effects on various materials. Specific needs and details of such testing must be evaluated on a site-specific basis.

### 9.6.5.1 Soil

The compatibility of soils with wastes is primarily concerned with the effects of the presence of liquid wastes in the pore fluids of the soils. Compatibility effects may include chemical alteration of the soil itself or alteration of soil properties, such as permeability, compressibility, and strength (since many of the properties of soils depend on the characteristics of the pore fluids).

#### 9.6.5.1.1 Clay

Clay has traditionally been used for water containment because of the low permeability of most clays and clay mixtures. Recent evidence suggests that permeability and other properties are altered by liquid contaminants. Clays are subject to alteration by organic chemicals, pH changes, ion exchange, and so forth.

#### 9.6.5.1.2 Silt

Silt is a major constituent of alluvial soils and usually appears in combination with various amounts of clay and sand. The parent material from which the silt is derived will influence the effects of wastes on the alteration of silts. Concern for the alteration of silts relates more to structural and strength property changes, than to chemical changes.

#### 9.6.5.1.3 Sand

Sand used for bedding and drainage media must be evaluated for alterations that may affect its structural and fluid conductivity suitability. Tests using the liquid phase of hazardous wastes on sands to determine leaching, permeability, strength, and particle size changes should be performed.

#### 9.6.5.1.4 Gravels and Aggregates

Gravels used for structural and drainage systems must be evaluated for alterations that may affect their suitability. Aggregates used in Portland cement and asphaltic concrete products should be evaluated in the same manner as the gravels and sands.

### 9.6.5.2 Rock

In situ properties of rocks underlying or adjacent to hazardous wastes should be evaluated for potential effects of exposure to wastes. Alteration of strength, permeability, competence, and so forth should be considered.

Samples of rock removed from the site will be useful in determining some physical and chemical property changes in contact with wastes. However, the value of that determination is limited. The overriding concern should be with the behavior of the rock mass as a unit.

### 9.6.5.3 Materials

#### 9.6.5.3.1 Concrete

Cast-in-place and precast concrete products to be used in hazardous waste control systems must be evaluated for effects caused by the waste materials. The effects of some chemicals are known to cause expansion, cracking, spalling, surface deterioration, and dissolution of cement paste or matrix. A few standard methods for resistance of concrete to some chemical and physical stresses may be found in ASTM Vol. 04.02.

#### 9.6.5.3.2 Soil-Cement

Minor amounts of Portland cement may be added to soils to strengthen them and to reduce permeability of soil materials. An evaluation of the soil-cement system, using specimens from the mix-design procedures, must be made using contaminated soils or involving hazardous waste materials. Cement is often used to solidify contaminated materials. The solidification procedure should be evaluated for properties to remain within an allowable range over the long term.

#### 9.6.5.3.3 Portland Cement

There are many types of Portland cement and blended hydraulic cements. Some have properties that may be more or less resistant to chemical exposure to hazardous wastes. The compatibility of the cement products must be assessed and evaluated to make successful Portland cement concrete.

#### 9.6.5.3.4 Asphalt Cement

Many types of bituminous products or asphalt cement are used to control leakage. The alteration of properties, such as impermeability, by hazardous wastes must be evaluated to determine product suitability. Evaluation may involve visual observation of changes, as well as physical property changes measured according to ASTM procedures.

#### 9.6.5.3.5 Asphalt Stabilized Soils

Asphaltic cement may be added to soils for strengthening and reducing permeability. The appropriateness of this method must be evaluated by testing with hazardous waste to determine the alteration of the stabilized soil's properties.

#### 9.6.5.3.6 Metal Products

Metal products are mentioned in this subsection to draw attention to any materials that may be buried in soil or contaminated soil or exposed to hazardous wastes. Since exposure of metal products to hazardous waste materials is possible, the corrosion, deterioration, and alteration of the product or its function must be evaluated to determine the most suitable material or the need for an alternative.

#### 9.6.5.3.7 Plastic Products

A broad range of material compatibility information for plastics is available from manufacturers. The potential exposure of plastics to hazardous waste must be defined and the most suitable products tested. Adaptations of the U.S. EPA SW-846 Test Methods for Evaluating Solid Waste, Method 9090 for Flexible Membrane Liners, may be considered for testing plastics.

#### 9.6.5.3.8 Wood Products

Wood products and lumber that may be subjected to hazardous waste should be evaluated before use. Such evaluation is especially important if wood and lumber products are to be used structurally.

#### 9.6.5.3.9 Geotextiles

The use of woven and nonwoven geotextiles is common in hazardous waste facilities. The functions these synthetic fibrous materials provide may be altered by exposure to wastes. Geotextiles should be tested and evaluated for their continued ability to provide the functions required. The nature of geotextiles presents a challenging task to the development of meaningful test methods. The U.S. EPA, SW-846 Test Methods for Evaluation Solid Waste, Method 9090, may provide some guidance.

#### 9.6.5.3.10 Geomembranes

Flexible membrane liners or geomembranes are 10- to 100-mil thick sheets of polymeric materials. Compatibility test information and results for most polymeric materials are available from the manufacturers and some independent sources. An accepted method of test for geomembranes is the U.S. EPA Method 9090. Properties of membrane specimens are determined before and after soaking in the hazardous waste liquid, extract, or leachate. Another recommended test method for estimating long-term performance of membrane liners in a chemical environment is provided in Appendix D of National Sanitation Foundation (NSF) Standard 54 for Flexible Membrane Liners.

#### 9.6.5.3.11 Synthetic Drainage Media

In place of sand and gravel drainage systems, synthetic drainage media may be used. The synthetic media may be separated from the soil above and below by a geotextile fabric. The media may be polymeric mesh mat-like material with favorable strength and hydraulic properties. The material should be evaluated using methods similar to those used for geomembranes, since the materials used are similar.

## 9.6.6 Laboratory and Analyses Records

A general description of the laboratory recording procedures is presented below. Specific requirements may be established as contractual obligations with the laboratories (e.g., U.S. EPA's CLP). The user should be familiar with the contractual obligations for sample and data recording when using contract laboratories. Review of existing CLP recording requirements is beyond the scope of this subsection.

### 9.6.6.1 Sample Log

All samples should be recorded upon receipt at the laboratory. The sample should be logged into a bound record book and assigned a sequential identification number. The log should be used to track the sample through the laboratory by recording date received, date and location stored, date tested, and date disposed of. Chain of custody should be maintained on all samples throughout the process (see Sections 4, 5, and 6). The numerical identification should be used on all laboratory record sheets, together with other pertinent information such as project name and number and case number.

### 9.6.6.2 Data Sheets

The data and analysis results for each sample should be recorded on data sheets as the test is conducted. The format for specific test sheets may follow those presented in the ASTM standards, as applicable. Data sheets should be developed and consistently used for tests that do not have standards.

At a minimum, the following identifying information should be provided on each data sheet:

- Project name and number
- EPA authorization number or case number
- Sample identifier (number, location, depth, and name of sampler)
- Date of laboratory analysis
- Laboratory and analyst names

In addition to the identifying information, the data sheet should refer to the standard used including a specific statement of any deviations from the standard. Where standards are not available, a detailed description of the test method should be attached with the data sheets.

The data section of the sheet should be legibly completed without erasures. Any changes to the data should be done by crossing out the original entry, writing in the correction, and initialing it.

Calculations should be orderly and should be done on the data sheet or attached separately. Calculations should follow the same guidelines as for data recording (i.e., it should be legible without erasures).

### 9.6.6.3 Recordkeeping

Originals of all laboratory sheets and records should be retained in a secure file by the analyzing laboratory. Legible copies should be provided to EPA and its contractors, as required.

In addition to data sheets, all pertinent correspondence, chain-of-custody records, quality assurance records, and other records should be retained. Originals should be retained for the duration of the project including completion of any litigation.

## 9.7 REGION-SPECIFIC VARIANCES

Many of the methods and procedures discussed in this subsection have not been accepted as standard by the EPA CLP. Because information on variances is rapidly dated, users should consult with the laboratory in each EPA region to obtain clarification of specific regional variations. Changes in variances will be included in Revision 01 to this compendium.

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# SECTION 10

# SURFACE HYDROLOGY

**Note:** This section is organized by the topics "Flow Measurement" and "Sampling" for greater usefulness.

## 10.1 FLOW MEASUREMENT

### 10.1.1 Scope and Purpose

This subsection provides general guidance for the planning, method selection, and implementation of surface flow measurements for hazardous waste site field investigations that require information on flows for streams, rivers, or surface impoundments.

### 10.1.2 Definitions

**Flow (or Volumetric Flowrate)**
That volume of water which passes through a cross-sectional plane of a channel in some unit of time.

**Flow Measurement**
The act or process of quantifying a flowrate.

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. This person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

### 10.1.3 Applicability

This subsection discusses general and special flow-measurement techniques that may be applied to the majority of site field investigations. There is no universally applicable procedure, because flows must be measured under a variety of conditions. For any given site, the technique selected must be appropriate for that site's specific conditions. For example, the choice of flow-measurement device can depend on the following criteria:

- Is the flow continuous or intermittent?
- Is the flow channel open or closed?
- What is the channel geometry?
- Are there hydraulic discontinuities in the channel (standing waves, hydraulic jumps, dams, etc.)?
- Is there access to the channel at a suitable point for measuring flow?

- How often will flow measurements need to be made?
- Will the flow-measuring device require freeze protection or shelter?
- What water constituents may affect the reliability of the flow-measuring device? For example, will sediment in the stream clog flow tubes?
- Would there be a need for installing a more permanent flow measuring device for long-term surveys?
- Are utilities (electrical, air, or clean water) available onsite?

The following discussions apply only to water moving from one point to another, not to surface water lying still in an impoundment or liquid waste pond. Such water does not fit the flow definition cited above. Flowing water moves because it has a sloping surface that is subject to the pull of gravity and/or a pressure head. This movement from point to point is opposed by frictional forces between the water and the sides of the channel. This friction leads to wide variations in velocity over the cross-sectional plane of the channel. No matter which flow-measurement technique or device is chosen, it will have to accurately account for these variations. Field crews conducting flow measurements must be made aware of the strengths and limitations that apply to any flow-measurement technique.

Another type of "flow" not covered by the following discussion may be called "overland flow" or "emergent subsurface flow," wherein water moves across a land surface without being constrained by definable, continuous channel boundaries. Examples of this type of flow occur during floods or heavy storm runoffs. Such flows are mostly ephemeral, nonuniform, and very shallow. Since there is no definite cross-sectional measurement available, flow measurement by any of the following methods is not practical. Problems related to quantification of such flows are discussed in the *National Handbook of Recommended Methods for Water Data Acquisition* compiled by the Department of Interior's U.S. Geological Survey (USGS) staff.

### 10.1.4 Responsibilities

The SM is responsible for obtaining proper flow measurements. The most important tool in carrying out this responsibility is the site operations sampling plan. Details of this plan are site-specific, usually following a site reconnaissance by the site or field team leader.

The field team leader is responsible for implementing the requirements of the site operations sampling plan and for reporting any unusual conditions to the SM as soon as it becomes apparent that plan modifications may be needed. The field team leader must also make certain that all required documentation is properly originated, maintained, completed, and forwarded to the proper authorities.

The field investigation team is responsible for the actual installation of the proper equipment and the performance of flow measurements. Selected members of the work crew must be familiar with the objectives, the site operations plan, the equipment designated for use, the recordkeeping requirements, the appropriate safety measures, and the importance of accurate measurements.

## 10.1.5 Procedures

### 10.1.5.1 General Considerations

The planning, selection, and implementation of any flow-measurement program require careful consideration by qualified, experienced personnel. A preliminary site visit should be made to review actual conditions and to confirm or correct site plans, diagrams, or layouts.

The purpose of making flow measurements should be clearly defined before commencing this activity. Some common reasons for measuring flowrates include the following:

- Assessing impacts on receiving streams
- Acquiring data on flow volume, variability, and average rate to design and operate wastewater treatment facilities
- Determining compliance with load limitations placed on selected pollutants
- Flow-proportioning composites to comply with permit requirements that govern composite sampling
- Estimating chemical addition requirements or treatment costs for effective wastewater treatment
- Establishing the requirements for sampling frequency or the need for continuous monitoring of flowing streams

Whatever the reason for conducting flow measurements, the parties involved in such work must be made aware of the purpose, so that their contribution to this effort will be better defined. Most of the techniques described below depend on two critical measurements:

- The geometry of the cross-sectional plane through which the water is passing
- The velocity at which the water is moving, typically expressed in terms of length per unit of time (e.g., meters per second, feet per second)

At times, the velocity may drop to zero and the water may stand still. This phenomenon further divides surface flows into two distinct types: intermittent and continuous. The flow-measurement method chosen must be able to account for periods of zero flow whenever they occur. The measurements themselves may be made continuously using automatic instruments or intermittently by manual methods. Human observers must be aware of flow variations including periods of no flow. But other factors, such as the cost, accessibility, climate, available time for measurements, and the relative accuracy of measurement desired, will also contribute heavily to the choice of method used. The type of measurement technique used will ultimately depend on conditions encountered at each location.

### 10.1.5.2 Methods and Applications: General

Selection and implementation of flow-measurement practices require that consideration be given to the following issues that are common to all surface flow measurements at or near hazardous waste sites:

- Preventing the spread of contamination
- Minimizing the risk to health and safety
- Maintaining a high level of accuracy in measuring flows
- Causing the least possible disruption to onsite activities
- Reporting all readings in an organized fashion as required by the sampling plan
- Reducing, where possible, any additional long- and short-term impacts

For most sites, flow measurements are made in open channels that consist of a bed, two banks or sides, and a free or open water surface. The term also may apply to water movement through closed conduits or sewers that are flowing only partially full. The most typical cross-sectional shape encountered is either circular or rectangular. On occasion, measurements are taken in pressurized closed channels that are completely full of water at a pressure greater than atmospheric, either because of gravity or the use of pumps. Some of the measurement techniques described in the following discussion are applicable only to open channels, while others work only in closed channels. Some may be used in either type of channel. Also, some methods are best suited for making single measurements, while others work best on a continuous basis. Individual site conditions will determine the user's options. The most appropriate option is selected and incorporated into the site sampling plan.

Most flow measurements are based on determining two key variables cited in Subsection 10.1.5.1: cross-sectional area and velocity across that area. For open channels, especially the smaller ones, the cross section is often best measured directly using a meter or yardstick and weighted chains or lines. Care must be taken to find a location where the dimensions are not likely to change during the time period in which flow measurements will be taken. Width and depth are expressed in terms of meters or feet, and the cross-sectional area is expressed as square meters or square feet.

Velocity is determined using one of the methods that follow, either directly or by calculation, from head differential or pressure differential relationships. Units are commonly given in meters/sec or feet/sec for most flow velocities. When cross-sectional area and flow velocity are multiplied, their product is the volumetric flowrate, expressed as cubic meters/sec or cubic feet/sec for large flows and as liters/sec or gallons/mil for small flows.

At times, the entire flow from a discharge pipe or a notched weir or dam can be caught in a collector of known volume, such as a 5-gallon can or 55-gallon drum. By clocking the amount of time needed to fill the vessel, one may obtain a direct measurement of volumetric flowrate without resorting to cross-sectional area and velocity measurements. A minimum of 10 seconds to fill the container is recommended. Several fill-ups should be timed, and the results should be averaged to improve the quality of this measurement. But other means of flow measurement will be used more often than this direct estimate, which is valid only for flows between 0.06 liter/sec (1 gallon per minute (gpm)) and about 6.3 liter/sec (100 gpm).

The equipment listed in this subsection is the most commonly used at hazardous waste sites. For selected special applications, the reader should refer to Subsection 10.1.5.3.

**Current Meter:** A current meter can be a mechanical device with a rotating element that, when submerged in a flowing stream, rotates at a speed proportional to the velocity of the flow at that point below the surface. The rotating element may be either a vertical shaft or a horizontal shaft type. Meter manufacturers usually provide the user with calibration tables to translate rotation into linear speed in meters/sec or feet/sec (Price, undated).

Current meters can also be electromagnetic sensors where the passage of fluids between two electrodes in a bulb-shaped probe causes a disturbance of the electromagnetic field surrounding the electrodes. This disturbance generates a small voltage that can be made proportional to fluid velocity by internal electronic circuitry. A direct readout of velocity in meters/sec or feet/sec is provided for the user (Marsh-McBirney, undated).

**Applicability:** Vertical axis meters are more commonly used because they are simpler, more rugged, and easier to maintain than horizontal shaft meters. They also have a lower threshold velocity, on the order of 0.03 meters/sec (0.1 feet/sec). The electromagnetic current meters can be used in making measurements in situations where mechanical meters cannot function, such as weedy streams where mechaical rotating elements would foul. However, the electromagnetic meters must always be carefully aligned to be normal to the stream cross section, since the meter measures only one velocity vector (the one parallel to the probe's longitudinal axis). Current meters will operate at depths ranging from 0.1 meter (0.3 feet) to any depth where the meter can be held rigidly in place using cables or extension poles. For most hazardous site investigations, depths rarely exceed 2 or 3 meters (6.5 to 10 feet). Since current meters provide readings at a single point, the mean velocity must be based on multiple readings along a vertical line, or on a single reading that can be converted to an estimated mean velocity using standard coefficients. Methods for estimating mean velocity include the following:

- Six-tenths depth method – Uses the observed velocity at a point 0.6 of the total depth below the surface as the mean velocity for the vertical. Flow is calculated for each subsection defined by the verticals and is the product of the depth times the mean velocity for that subsection. Total discharge flow is the sum of all individual subsection flows, while the average stream velocity is that sum (total discharge) divided by the total cross-sectional area. The number of readings to be taken to increase accuracy will depend on the width of the stream, from 2 or 3 for streams less than 5 feet across to 15 to 25 for streams wider than 50 feet across. Ideally, the stream should be partitioned into sections small enough that less than 10 percent of the total stream flow passes through each section. In this manner, individual measurements that may be in error will have less impact on the overall average velocity determination. However, practical consideration, such as a rapidly changing stage or limited time available to conduct measurements, often may preclude the use of the ideal number of partial sections. Users must recognize the potential impact on the overall accuracy of velocity measurements from an inadequate number of verticals within a given cross section. This method works best at depths between 0.09 and 0.16 meters (0.3 to 2.5 feet) and is the method of choice when measurements must be made quickly.

- Two-point method – Measures velocities at 0.2 and 0.8 of the total depth below the surface. The average of the two readings is considered to be the average for the vertical. Several different verticals are averaged across the cross section. This method is more accurate than the six-tenths depth method, but it cannot be used at depths less than 0.76 meters (2.5 feet) because the observation points would be too near the surface and the streambed.

- Three-point method – Measures velocities at 0.2, 0.6, and 0.8 of the total depth below the surface. Readings at 0.2 and 0.8 are averaged; then that result is averaged with the reading at 0.6. This method provides a better mean value when velocities in the vertical are abnormally distributed, but it should not abnormally be used at depths less than 0.76 meters (2.5 feet).

- Vertical-velocity method – Primarily for deep channels, this method measures velocities at 0.1 depth increments between 0.1 and 0.9 of the total depth for several verticals. Because of the multiplicity of readings, this method is rarely used.

A step-by-step summary of a typical flow or discharge measurement is as follows:

- Assemble current meter and test for proper operation in accordance with the manufacturer's instructions. Collect data form or notebook, pencil, stop watch, 50-foot tape, etc.

- Partition stream into sections (with tag-line or bridge railing), visually observing the velocity and general flow of the stream. Enough stations should be established to prevent more than 10 per cent of the total discharge from passing through any individual partial section. Remember, the partial section in question is not the same as the interval between two successive stations. Mark stations appropriately. A check of measurements may indicate the need for readjustment of the partitioned sections to upgrade the quality of the readings.

- Record stream stage as indicated by one of the staff gauges, and record this value on the water level recorder chart at the point of pen contact.

- Record a minimum of the following items on the data form or in the notebook:

    - Project
    - Site
    - Date
    - Time at start of measurements
    - Stream stage at start of measurements
    - Approximate wind direction and speed
    - General stream condition (e.g., turbid, clear, low level, floating debris, water temperature, type of streambed material, etc.)
    - Other factors having a bearing on discharge measurements
    - Location of initial point
    - Total width of stream to be measured
    - Type of current meter and conversion factor, if applicable
    - Name of investigator taking the above reading

- Determine the depth and mean velocity at the first station or "initial point" if the situation allows; record this information.

- Measure depth at the second station from initial point and record. Determine whether the velocity should be measured at the 0.6 depth from the surface (six-tenths depth method), at the 0.2 and 0.8 depths (two-point method), or by either of the other methods available. Calculate respective depths from the surface, measure the velocity at each point, and record these values.

- Continue to each successive station as rapidly as possible, following the same procedure.

- Determine the depth and mean velocity at the last station, or endpoint, and record.

- Record on the data form the ending time of this series of measurements and the stage, since the stage may have been changing during the measurements.

- Enter the ending stage value on the recorder chart at the point of pen contact. This information will illustrate the interval of time and stage variations during the cross-sectional measurements. Also enter the date and indicate that a calibration has taken place over this interval.

- Remove the tag-line (if used); rinse the current meter in clean water, if necessary; allow the current meter to dry; then pack it away in its carrying case.

There are a few other comments regarding stream discharge calibrations that should be mentioned:

- Where practical, make the measurements with the investigator standing behind and well to the side of the meter.
- Avoid disturbing or standing along the streambed beneath the cross-sectional measuring points. This location is part of the control area and should remain constant, if possible, from calibration to calibration of the stream. This step is especially important if soft, mucky sediment is encountered somewhere along the cross section.
- Where possible, try to use the same cross section throughout the study period and during all of the stream calibrations. However, the number and position of stations within the cross section may be changed, if necessary, to accommodate changing flow conditions.
- Always hold the wading rod vertical, and be aware of how $V_{\mathrm{NORM}}$ is determined with each of the various types of meters, if it becomes necessary to switch meters during a calibration.
- Repeat the stream calibration at regular intervals throughout the study period to account for seasonal changes in streambank vegetation and streambed alterations that may affect measurements.

Once the mean velocity for each stream subsection is determined, that value is multiplied by the area of the subsection; the product is the volumetric flow through the subsection per unit of time. The total discharge rate is the sum of all volumetric flows for each subsection across the entire cross section of the stream. The reader should refer to USGS Water Supply Paper 2175 for additional information (USGS, 1982). Customary units are cubic meters/sec (cm ft/sec) for large flows and liters/sec (gal/mil) for small flows.

**Current Meters and Stage Gauges:** Where repeated measurements of a volumetric flowrate at a certain cross-sectional area are required, it is best to install a permanent stage gauge along the stream's back or side wall to facilitate measurement of the depth. The gauge should be a rigid rod or board, precisely graduated and firmly mounted with the streambed serving as a possible reference point. Where stream characteristics are such that significant bed erosion from scouring may be expected, it is best not to set the streambed as a zero point, because this could lead to confusion from generation of negative numbers for gauge height readings. An arbitrary datum plume should be selected that is below the elevation of zero flow expected for the stream site. Gauges may be mounted vertically (perpendicular to the stream surface) or may incline along the slope of the stream bank. Vertical gauges are simpler to construct and calibrate, while inclined gauges provide more accurate readings and are less likely to be damaged by material floating by. The gauge provides one of the measurements needed to estimate area. Width is fixed for channels with vertical sides and can be readily determined for other configurations. Velocity is determined using a current meter as described above.

Discharge rating curves can be used to define the relationship between stage and stream discharge, and to allow conversion of stage hydrographs to discharge hydrographs. The discharge calibration points are hand or machine plotted onto a log-log paper graph of stage versus stream discharge. Stream stage is plotted on the vertical $Y$ axis, and stream discharge is plotted on the horizontal $X$ axis. Ideally, enough calibrations are conducted over the full range of stage variations to allow a smooth hand-drawn curve to be drawn through these points on the graph.

The slope and rate of change of slope may vary significantly over the length of this curve. At certain gauging stations, the slope of this curve may break sharply, or the distribition of points may require the construction of two partial curves rather than one continuous curve. These latter two situations would apply to more complex stage discharge relationships. It is the task of the investigator to derive a mathematical relationship that describes this curve as closely as possible (i.e., an equation). The development of an equation would allow calculation of discharge flow by simply plugging in the stream elevation. This equation will allow computerization of the process of converting stage records into discharge and will eventually allow conversion to volume by noting the time interval on the recorder chart at which this rate of flow applies.

More complicated rating relationships may be required at a particular gauging station. Discharge may be not only a function of stage but also a function of slope, rate of change of stage, or other variables specific to each site. Additionally, stage-discharge relationships are rarely permanent, and discharge calibrations should be carried out at periodic intervals to define the effects of various factors including the following:

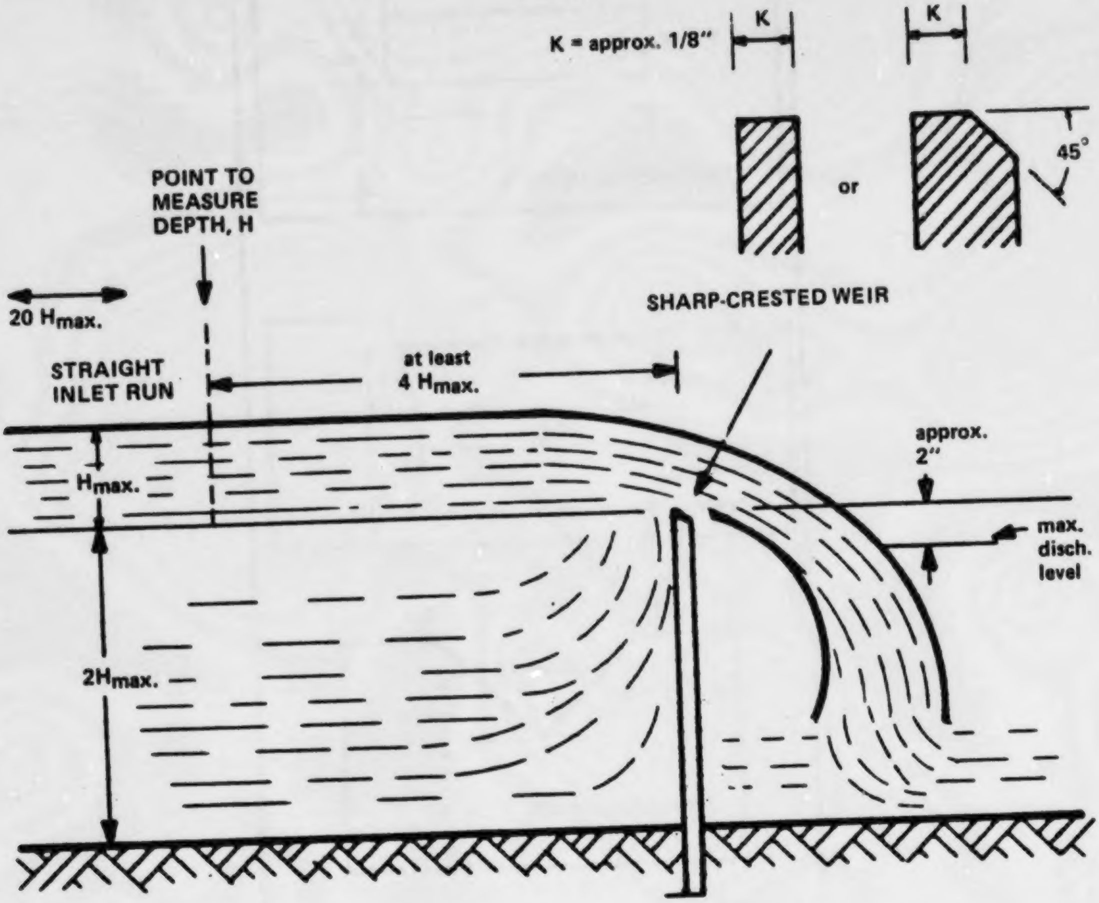
- Scouring and deposition of sediment
- Alteration of streambed roughness as a result of the creation and dissemination of dunes, antidunes, ripples, and standing-wave features in sandy bottoms; the deposition of leaves and other debris during different seasons; and the seasonal variation in the growth of macrophytes
- Ice effects that may cause additional resistance to flow (If monitoring is carried out during the colder months, a complete ice-over and additional freeze will tend to constrict the stream channel with time and may increase the stage, when in fact the flow may not be increasing at all.)
- Human-related activities, such as upstream construction, recreation, etc.

**Applicability:** This method applies to sites where many flow measurements will be made over a long period of time. Care must be taken to maintain a known zero reference point elevation. The point does not have to be the stream's bottom. Where bed erosion over the course of flow measurements may become a problem, provisions must be made to recalibrate the gauge at regular intervals (e.g., weekly). The gauge is lowered or raised as necessary to conform with changing bed conditions. Calculation of flow rate is the same as in the preceding subsection for current meters alone.

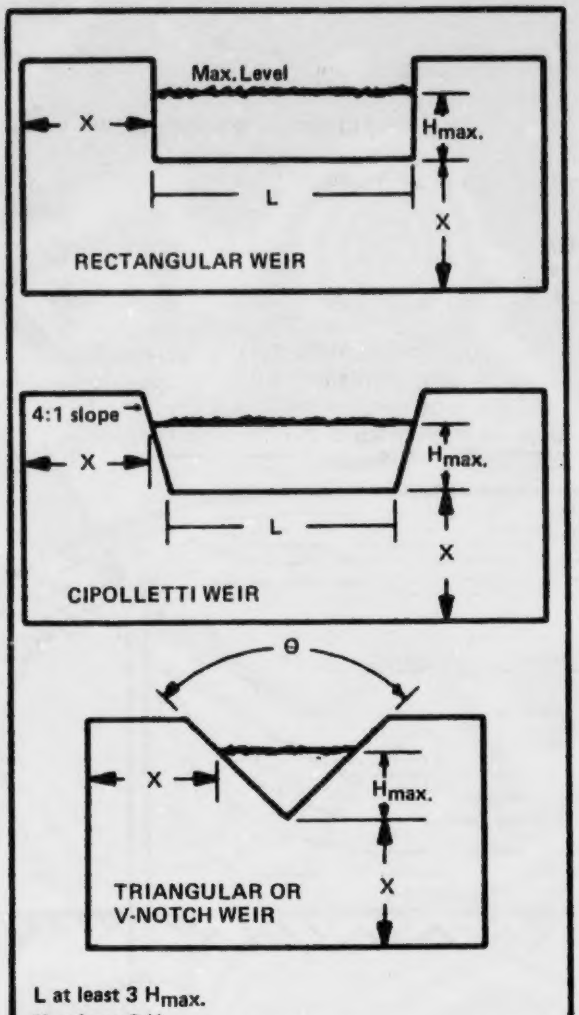
**Weirs:** Weirs are commonly used flow measurement devices. They are relatively easy to install and inexpensive to construct. All weirs are deliberate restrictions inserted into an open channel or a partially full pipe to obstruct flow by forcing the weir through a calibrated cross section. The weir causes water to back up and create a higher level (head) than the level below the barrier. The height of that head is a function of the velocity of the flow. Standard tables and nomographs are available for many different types of weirs, based on different general equations for each type. The reader should refer to Exhibit 10-1 for a typical profile of an installed weir.

The three most common weir configurations are triangular (or V-notch), rectangular, and Cipolletti (or trapezoidal). The reader should refer to Exhibit 10-2 for examples. Triangular weirs can have submerged angles of any size, but the most common angles are 22-1/2:, 30:, 45:, 60:, and 90:. Rectangular weirs may be designed with no end contractions (the water flows over the full width of the weir) or with contractions on one or both ends (water flows over a notch in the weir). The former case is referred to as a surpressed weir, but this type is often subject to problems when a vacuum develops under the nappe (the sheet of water breaking free from the crest of the weir). The most common type of rectangular weir is the contracted or notched weir with end contractions. Standard contracted weirs have two end contractions whose width is at least twice the maximum head expected above the weir crest. The Cipolletti weir has standardized end slopes of one horizontal to four vertical, which provide a correction for the contraction of the nappe over the crest. Other weir profiles exist, but they are much less common. The reader should refer to the flow-measurement references in U.S. Department of Interior (USDA), 1974; Instrument Specialists Company (ISCO), 1985; and USGS, 1982, for information on other types of weirs.

## Exhibit 10-1
## PROFILE OF SHARP-CRESTED WEIR


K = approx. 1/8"
K
K
or
45°
POINT TO MEASURE DEPTH, H
20 Hmax.
SHARP-CRESTED WEIR
STRAIGHT INLET RUN
at least 4 Hmax.
approx. 2"
Hmax.
max. disch. level
2Hmax.

## Exhibit 10-2
## THREE COMMON TYPES OF SHARP-CRESTED WEIRS


Max. Level
X
$H_{max.}$
L
X
RECTANGULAR WEIR
4:1 slope
X
$H_{max.}$
L
X
CIPOLLETTI WEIR
θ
X
$H_{max.}$
X
TRIANGULAR OR
V-NOTCH WEIR

L at least 3 $H_{max.}$
X at least 2 $H_{max.}$

**Flumes:** Flumes are specially shaped open-channel flow sections with a restriction in channel area and, in most examples, with a change in channel slope. Either or both of these shape changes cause velocities to increase and water levels to change while passing through the flume. Typical flumes consist of three sections:

- A converging section to accelerate the approaching flow
- A throat section, whose width is used to designate flume size
- A diverging section, designed to ensure that the level downstream is lower than the level in the converging section

Ideally, flowrate through a flume may be determined by measurements at a single point some distance downstream from the inlet and above the throat. This single measurement indicates the discharge rate only if critical or supercritical flow is achieved in the flume. By definition, critical flow is that for which the Froude number (the ratio of force due to inertia to the force due to gravity) is unity. Supercritical flow occurs when the Froude number exceeds unity. If the Froude number is less than one, subcritical flow occurs; a second depth reading must be taken in the throat section to determine the true discharge rate. Refer to USGS Water Supply Paper 2175, Volume 2, Chapter 10, for discussion of flumes and weirs under all flow conditions, including submergence.

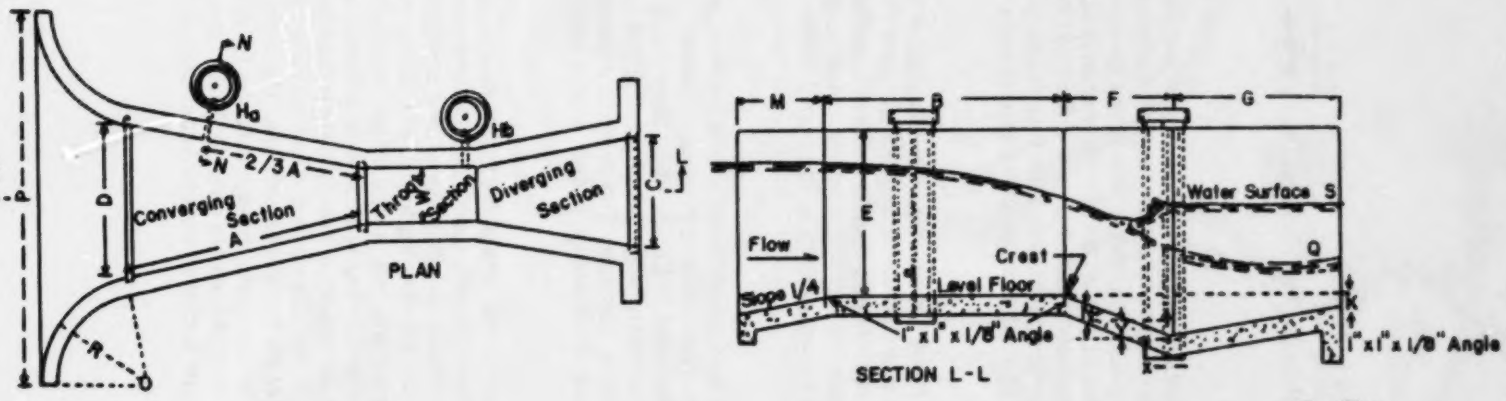
The most widely used flume type is the Parshall flume. These flumes may be constructed of wood, fiberglass, concrete, plastic, or metal. The dimensions and capacities for 12 different standard Parshall flumes are given in Exhibit 10-3. The reader should note that considerable overlap exists in capacities, indicating that several different sizes can apply to most flow measurement requirements. Flow curves for free-flow conditions are shown in Exhibit 10-4 for 17 Parshall flumes, ranging in size from 3 inches to 50 feet.

Another useful, more portable flume is the Palmer-Bowlus type, which uses the existing channel configuration, but provides a level section of floor and some side contraction to produce supercritical flow. Four commonly used shapes of Palmer-Bowlus flumes are illustrated in Exhibit 10-5. Note that in each case, the floor length is approximately the same as the channel width. Materials of construction include fiberglass, stainless steel, cast iron, or, for permanent installations, concrete. The principal advantage of Palmer-Bowlus flumes is their ease of installation, while the main disadvantage is their smaller useful flow range.

For measurement of low flowrates (less than 2.8 $m^3$/sec or 100 cfs), one of the H-type flumes may be used. These flumes are more nearly weirs than flumes or are more properly called open-channel flow nozzles, but they are included with flumes because of historical precedence. Because of their configuration, design of these flumes combined the accuracy of a weir with the self-cleaning feature of a flume. H-type flumes have the advantage of simple construction and can monitor flow over a wide range. They have flat, unobstructed bottoms, sloping side contractions (much like the converging section of a flume), and a trapezoid-shaped opening that tilts backwards toward the approaching flow. This opening is the flow control section; the flowrate is a function of the convergence angle, the side wall top slope, and the width of the opening. H-type flume size is designated by the depth, $D$, of the flume at its entrance. There are three basic configurations of H-type flumes, ranging from H flumes for low flows, through H flumes for medium flows, to H flumes for high flows. Dimensions and capacities for H flumes are given in Exhibit 10-6. The reader should consult standard flow references or manufacturers' published data for information on other H-type flumes.

## Exhibit 10-3

## DIMENSIONS AND CAPACITIES OF THE PARSHALL MEASURING FLUME, FOR VARIOUS THROAT WIDTHS, *W*



N
$H_a$
$H_b$
L
L
D
2/3 A
Converging Section
A
Throat Section
W
Diverging Section
C
R
PLAN
M
B
F
G
E
Flow
Water Surface S
Q
Crest
Level Floor
Slope 1/4
1" x 1" x 1/8" Angle
1" x 1" x 1/8" Angle
K
X
SECTION L-L

| *W* | | *A* | | *⅔ A* | | *B* | | *C* | | *D* | | *E* | | *F* | | *G* | | *K* | *N* | *R* | | *M* | | *P* | | *X* | *Y* | Free-Flow Capacity (Second-Foot *) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ft | In. | Ft | In. | Ft | In. | Ft | In. | Ft | In. | Ft | In. | Ft | In. | Ft | In. | Ft | In. | In. | In. | Ft | In. | Ft | In. | Ft | In. | In. | In. | Minimum | Maximum |
| 0 | 3 | 1 | 6⅜ | 1 | ¼ | 1 | 6 | 0 | 7 | 0 | 10 3/16 | 2 | 0 | 0 | 6 | 1 | 0 | 1 | 2¼ | 1 | 4 | 1 | 0 | 2 | 6¼ | 1 | 1½ | 0.03 | 1.9 |
| 0 | 6 | 2 | 7/16 | 1 | 4 5/16 | 2 | 0 | 1 | 3½ | 1 | 3⅝ | 2 | 0 | 1 | 0 | 2 | 0 | 3 | 4½ | 1 | 4 | 1 | 0 | 2 | 11½ | 2 | 3 | 0.05 | 3.9 |
| 0 | 9 | 2 | 10⅝ | 1 | 11⅛ | 2 | 10 | 1 | 3 | 1 | 10⅝ | 2 | 6 | 1 | 0 | 1 | 6 | 3 | 4½ | 1 | 4 | 1 | 0 | 3 | 6½ | 2 | 3 | 0.09 | 8.9 |
| 1 | 0 | 4 | 6 | 3 | 0 | 4 | 4⅞ | 2 | 0 | 2 | 9¼ | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 9 | 1 | 8 | 1 | 3 | 4 | 10¾ | 2 | 3 | 0.11 | 16.1 |
| 1 | 6 | 4 | 9 | 3 | 2 | 4 | 7⅞ | 2 | 6 | 3 | 4⅜ | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 9 | 1 | 8 | 1 | 3 | 5 | 6 | 2 | 3 | 0.15 | 24.6 |
| 2 | 0 | 5 | 0 | 3 | 4 | 4 | 10⅞ | 3 | 0 | 3 | 11½ | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 9 | 1 | 8 | 1 | 3 | 6 | 1 | 2 | 3 | 0.42 | 33.1 |
| 3 | 0 | 5 | 6 | 3 | 8 | 5 | 4¾ | 4 | 0 | 5 | 1⅞ | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 9 | 1 | 8 | 1 | 3 | 7 | 3½ | 2 | 3 | 0.61 | 50.4 |
| 4 | 0 | 6 | 0 | 4 | 0 | 5 | 10⅝ | 5 | 0 | 6 | 4¼ | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 9 | 2 | 0 | 1 | 6 | 8 | 10¾ | 2 | 3 | 1.3 | 67.9 |
| 5 | 0 | 6 | 6 | 4 | 4 | 6 | 4½ | 6 | 0 | 7 | 6⅝ | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 9 | 2 | 0 | 1 | 6 | 10 | 1¼ | 2 | 3 | 1.6 | 85.6 |
| 6 | 0 | 7 | 0 | 4 | 8 | 6 | 10⅜ | 7 | 0 | 8 | 9 | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 9 | 2 | 0 | 1 | 6 | 11 | 3½ | 2 | 3 | 2.6 | 103.5 |
| 7 | 0 | 7 | 6 | 5 | 0 | 7 | 4¼ | 8 | 0 | 9 | 11⅜ | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 9 | 2 | 0 | 1 | 6 | 12 | 6 | 2 | 3 | 3.0 | 121.4 |
| 8 | 0 | 8 | 0 | 5 | 4 | 7 | 10⅛ | 9 | 0 | 11 | 1¾ | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 9 | 2 | 0 | 1 | 6 | 13 | 8¼ | 2 | 3 | 3.5 | 139.5 |

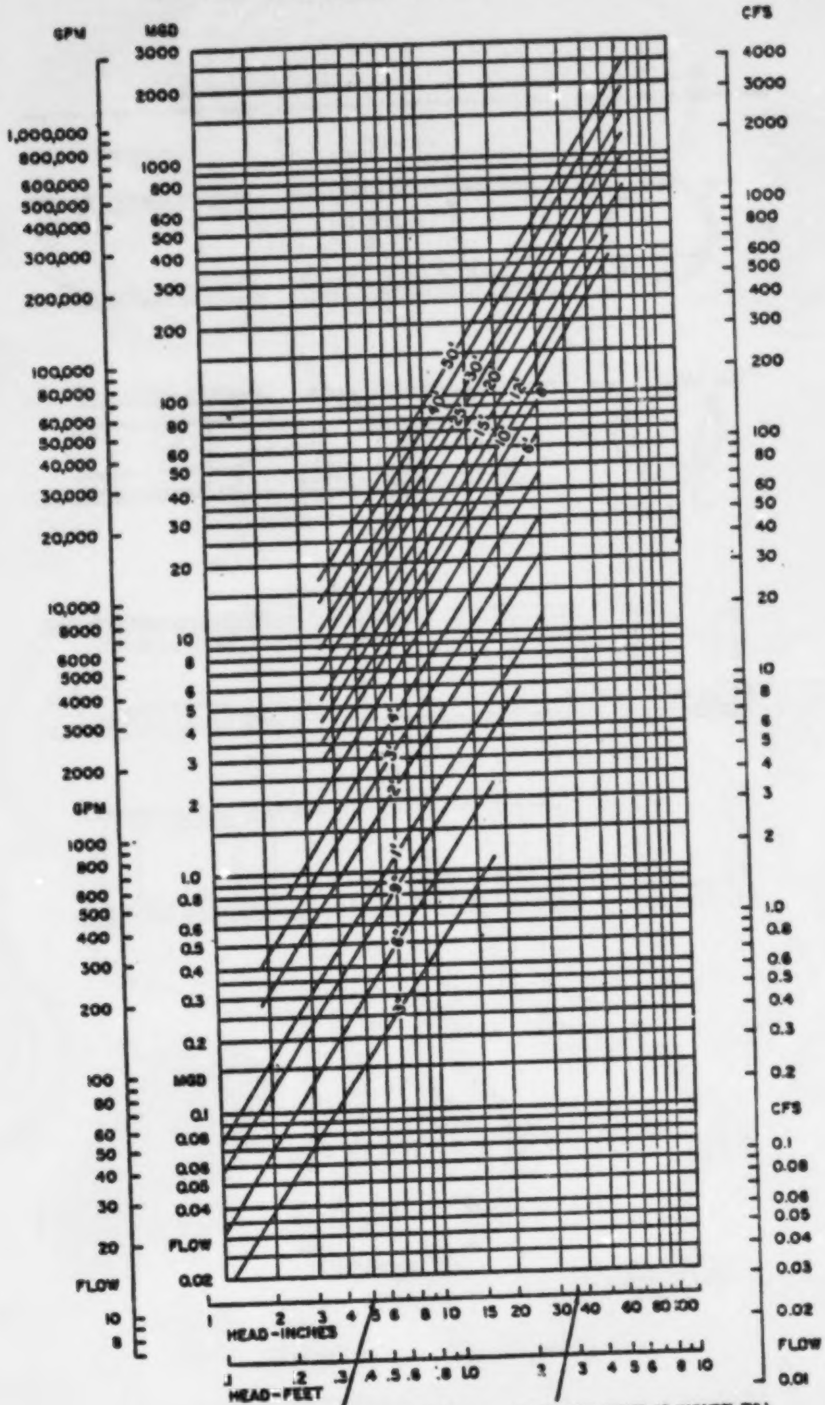
* Equals 1 cu ft per sec.

LEGEND:

| | |
|---|---|
| *W* | Size of flume, in inches or feet. |
| *A* | Length of side wall of converging section. |
| *⅔ A* | Distance back from end of crest to gage point. |
| *B* | Axial length of converging section. |
| *C* | Width of downstream end of flume. |
| *D* | Width of upstream end of flume. |
| *E* | Depth of flume. |
| *F* | Length of throat. |
| *G* | Length of diverging section. |
| *K* | Difference in elevation between lower end of flume and crest. |
| *N* | Depth of depression in throat below crest. |
| *R* | Radius of curved wing wall. |
| *M* | Length of approach floor. |
| *P* | Width between ends of curved wing walls. |
| *X* | Horizontal distance to $H_b$ gage point from low point in throat. |
| *Y* | Vertical distance to $H_b$ gage point from low point in throat. |

Source: *ORSANCO* (1952).

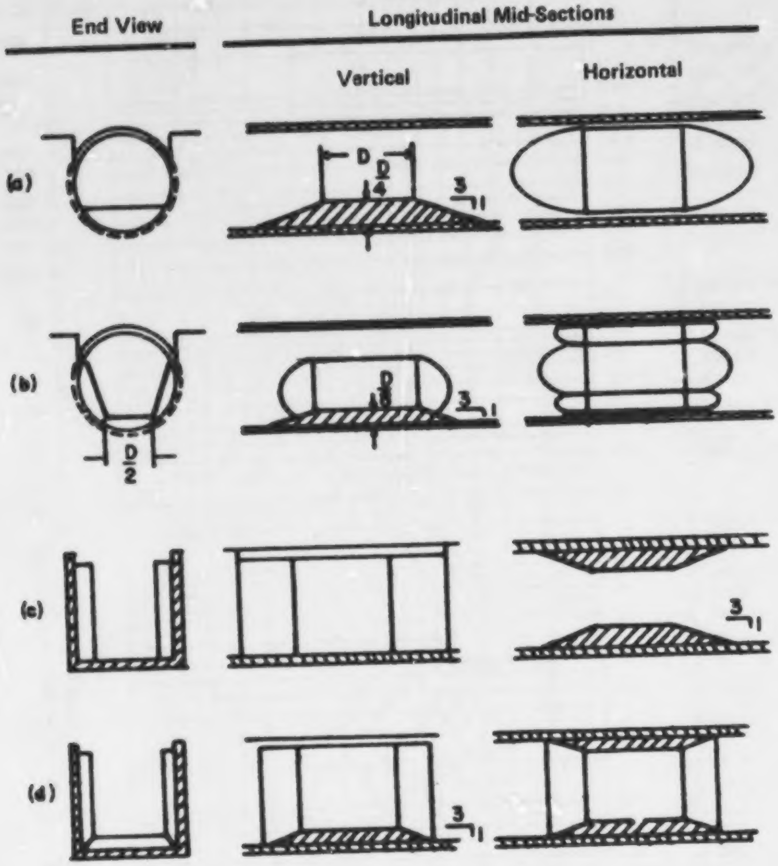
## Exhibit 10-4
## FLOW CURVES FOR PARSHALL FLUMES



FIVE INCHES IS MINIMUM FULL SCALE HEAD WITH FOXBORO FLOAT AND CABLE METER.

THIRTY-SIX INCHES IS MAXIMUM FULL SCALE HEAD WITH FOXBORO FLOAT AND CABLE METER.

## Exhibit 10-5
## VARIOUS SHAPES OF PALMER-BOWLUS FLUMES


End View
Longitudinal Mid-Sections
Vertical
Horizontal
(a)
D
D/4
3/1
(b)
D/8
3/1
D/2
(c)
3/1
(d)
3/1

**Applicability:** Flumes are more versatile than weirs, in that they can be used to measure higher flowrates than comparably sized weirs; they are, to a large extent, self-cleaning because of higher velocities through the throat section. They also operate with much smaller head losses than weirs. Their major disadvantage is the cost of construction and installation. As a result, flumes tend to be used only where many measurements over a long period of time are contemplated. Another disadvantage is their insensitivity at low flows because of the rectangular section.

In most cases, the smallest flume that can handle the maximum expected flow is chosen, but the channel width should also be considered when selecting a flume size. Generally, the flume's width should be one-third to one-half of the channel width.

Palmer-Bowlus flume flowrates are best estimated from discharge tables published by the flume manufacturers. The reader should note that tables covering flumes made by one manufacturer may not apply to those of another manufacturer because of subtle discrepancies in shape or physical dimensions. Also, field calibrated tests of flumes have indicated up to a 7 percent difference at low heads between actual and theoretical discharge rates. For Palmer-Bowlus flumes in general, the following equations state some of the applicable relationships:

$$\frac{Q^2}{g} = \frac{Ac^3}{b} \quad \text{and} \quad \frac{Vc^2}{2g} = \frac{Ac}{2b} = \frac{dc}{2}$$

Where:

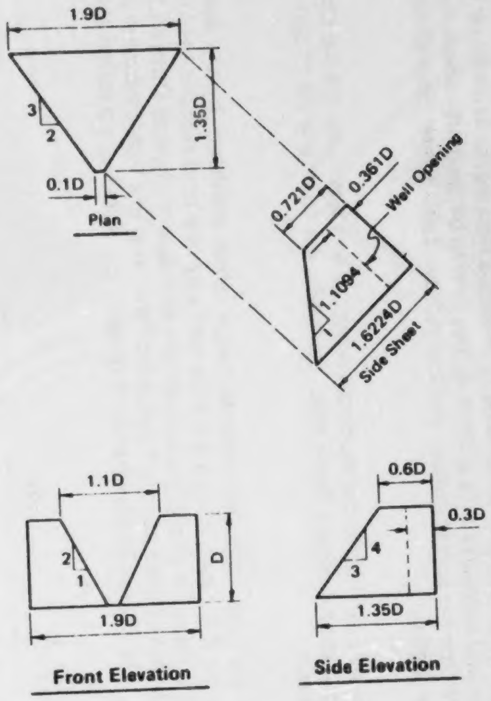
$Ac$ = area at the critical depth in $\text{ft}^2$
$Q$ = discharge flow in cfs
$g$ = 32.2 $\text{ft/sec}^2$ (acceleration because of gravity)
$b$ = width of the flume in ft
$Vc$ = critical velocity in ft/sec
$dc$ = critical depth in ft

Discharge equations have been developed for various H-type flumes by Gwinn and Parsons. These are quite complex and are not listed here. For further details on HS, H, and HL flumes, the reader should refer to Subsection 10.1.7.

**Submerged Orifices:** An orifice flow-measuring device consists of a well-defined, typically circular or rectangular hole that is designed to restrict flow when installed in a pipe or on a wall or bulkhead through which flow can occur. Orifices may discharge freely into air or into water as a submerged flow. The submerged orifice is more likely to be used in field investigations, especially where there is insufficient fall for a weir, and a flume cannot be justified. As in the case of weirs, installation of thin plate orifices is relatively inexpensive and simple, and variations in flowrate are easily accommodated by varying the size or shape of the orifice. Exhibit 10-7 illustrates four common types of orifices: the sharp-edged, the rounded, the short tube, and the Borda-type orifices. The reader should note that each offers different resistances to flow even though the diameters are identical. The coefficient, $C$, shown for each type is used in calculations to account for the different resistances.

**Applicability:** Submerged orifices may be used to measure flows where the opening can be kept full of water and where the pressure head upstream and downstream of the orifice can be measured. If the upstream water surface drops below the top of the orifice, flow will cease to follow the laws of orifice flow. Instead, the partly submerged orifice will begin to function more like a weir. Orifices should be installed in straight sections of the channel or pipe. Orifice diameter (or area for noncircular orifices) is a function of the expected flow and may range in size from 10 percent to 90 percent of the cross sectional area. Flows are estimated by measuring the pressure differential upstream and downstream, then relating this dif-

## Exhibit 10-6
## DIMENSIONS AND CAPACITIES OF H-TYPE FLUMES

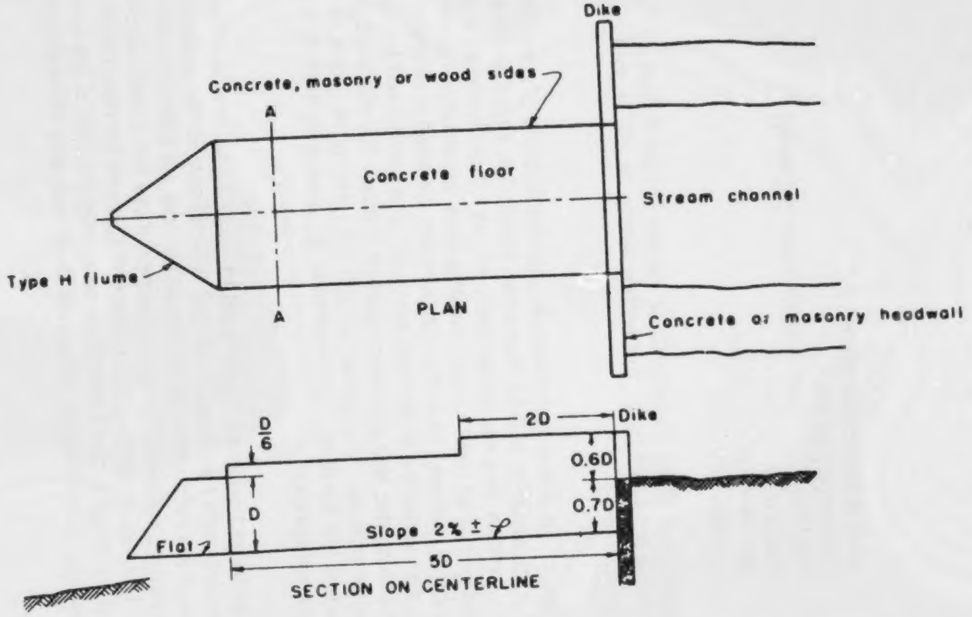

1.9D
3
2
1.35D
0.1D
Plan
0.721D
0.361D
Well Opening
1.1094
1.6224D
Side Sheet
1.1D
2
1
D
1.9D
Front Elevation
0.6D
0.3D
4
3
1.35D
Side Elevation

### Proportions of the Type H Flume

Approximate Capacities

| Depth-D Feet | Capacity FT.$^3$/s |
|---|---|
| 0.5 | 0.3+ |
| 0.75 | 1- |
| 1.0 | 2 |
| 1.5 | 5+ |
| 2.0 | 11 |
| 2.5 | 19 |
| 3.0 | 30+ |

Note: For flumes less than 1 foot deep, the length of flume is made greater than 1.35D so that the float may be attached.


Dike
Concrete, masonry or wood sides
A
Concrete floor
Stream channel
Type H flume
A
PLAN
Concrete or masonry headwall
D
6
2D
Dike
0.6D
D
0.7D
Slope 2% ± ℓ
Flat
5D
SECTION ON CENTERLINE

STRAIGHT HEADWALL INSTALLATION
(for use when flume is to be installed in a well-defined natural channel)

ference to the geometry of the orifice and channel cross section. For most applications the general equation is $Q = CAK (H_1 - H_2)^{0.5}$, where $Q$ is the discharge rate in cfs, $A$ is the orifice area in ft$^2$, $H_1$ is the pressure head at the center of the inlet to the orifice (in feet), $H_2$ is the pressure head downstream of the orifice (in feet), and $C$ and $K$ are constants derived from orifice shape and geometry. Values of $K$ may be calculated from the equation

$$K = \left[\frac{2g}{1 - \left(\frac{d_2}{d_1}\right)^{4}}\right]^{0.5},$$

where $g$ = 32.2 ft/sec$^2$ (acceleration as a result of gravity), $d_2$ is the orifice area in square feet and $d_1$ is the channel cross-sectional area in square feet. Alternatively, $K$ may be approximated from the curve shown as Exhibit 10-8 for known values of $d_1$ and $d_2$. The coefficient $C$ will be relatively constant for most $d_2/d_1$ ratios, but it will tend to increase for $d_2/d_1$ ratios greater than 0.7. For example, the 0.61 coefficient used with sharp-edged orifices covers all $d_2/d_1$ ratios from 0.2 through 0.7, but it increases to 0.64 for the case where $d_2/d_1 = 0.8$, and to 0.71 when $d_2/d_1 = 0.9$. In most cases, the orifice-to-channel ratio will be less than 0.5, so the coefficient shown in Exhibit 10-8 will apply.

**Water Stage Gauges, Recorders and Stilling Wells:** In those instances where many repeated flow measurements are to be made over a period of time, or where continuous flow readings are desired, it becomes necessary to provide a means for measuring surface elevation more efficiently. Water surface elevation is the variable parameter for most applications, because the channel cross-sectional area at a given point is usually fixed. Three ways of simplifying the measurement of surface water elevation are as follows:

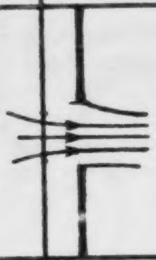
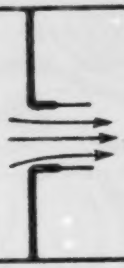
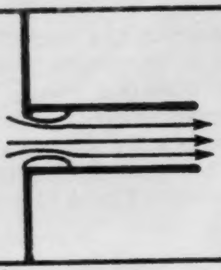
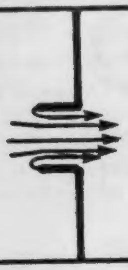
- Installation of permanent water stage gauges at points where surface elevation readings are necessary
- Provision for automatic recorders that can track changes in elevation on a continuous basis
- Installation of stilling wells for improving the reliability of surface-level measurements

Water stage gauges were discussed previously as an adjunct to the use of current meters, but they are readily adapted to weirs and flumes as well. The graduated face of the gauge must be kept clean to observe the readings accurately. In addition to permanently mounted staff gauges, other types of calibrated gages may be used (e.g., hook gauges, wire-weight gauges with graduated disk readouts, wire-tape gauges, and chain gauges). All are designed to provide reference points so that surface elevations can be more easily measured, but none allows for continuous measurements, because they are all dependent on human observers.

Automatic recording devices can provide continuous readings of surface elevation by using graphic, punched tape, or printed records of the rise and fall of the water surface. A common type of graphic recorder uses a weighted float and cable to rotate a float pulley, which in turn is linked to a flow cam and base plate that cause a pen to move up or down the face of a recorder chart (Stevens, 1976). The reader should refer to Exhibit 10-9 for a simplified sketch of this device. USGS prefers a digital punch-tape recorder because of its greater economy and flexibility and its compatibility with the use of computers to calculate discharge records. The stages are recorded in increments of 0.01 feet and are transmitted to the recorder by rotation of an input shaft. Shaft rotation is converted by the instrument into a coded punch-tape record. For details, the reader should refer to USGS Water Supply Paper 2175 (USGS, 1982). Other similar

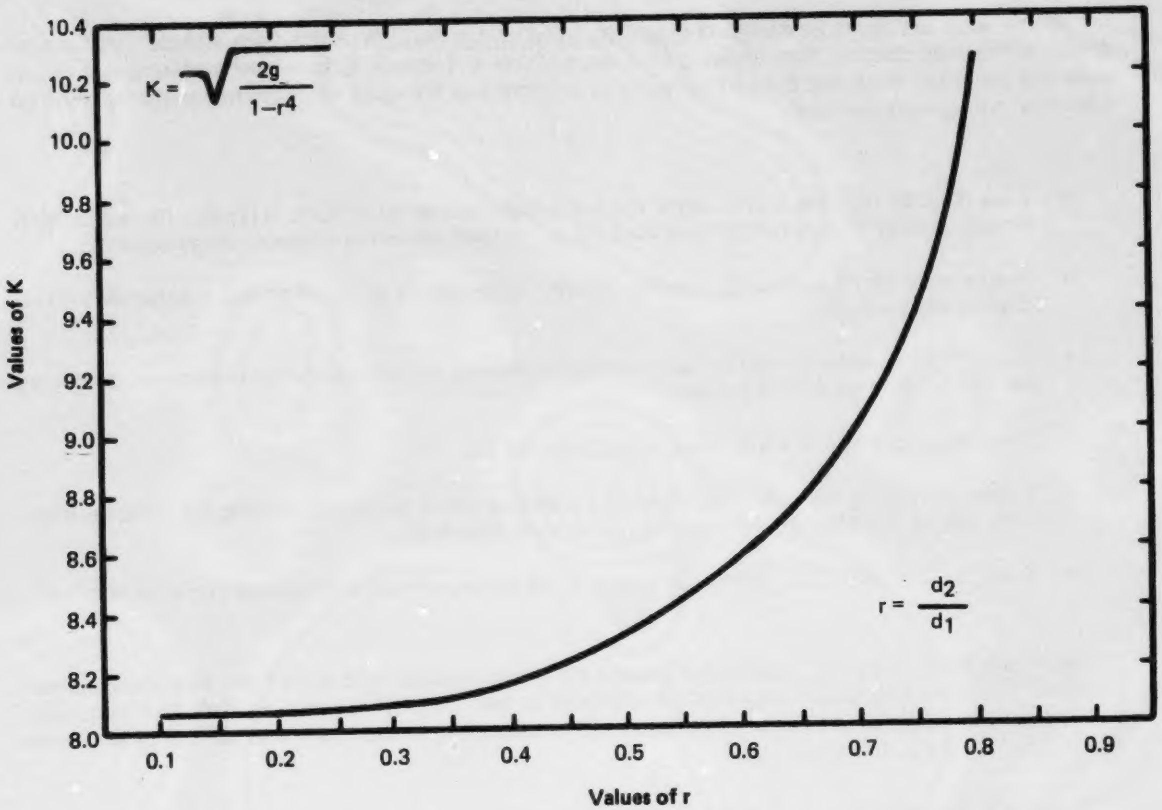
## Exhibit 10-7
## COEFFICIENTS OF FOUR TYPES OF ORIFICES

**ORIFICES AND THEIR NOMINAL COEFFICIENTS**

| | Sharp-Edged | Rounded | Short-Tube | Borda |
|---|---|---|---|---|
| |  |  |  |  |
| C | 0.61 | 0.98 | 0.80 | 0.51 |

## Exhibit 10-8

## CURVE FOR DETERMINING THE VALUES OF *K* USED IN THE ORIFICE, VENTURI, AND FLOW NOZZLE EQUATIONS



recorders sense changes in pressure at the water surface. A box containing a flexible diaphragm is mounted at the water surface so that the rise and fall of the surface will increase or decrease the pressure on the diaphragm. These changes in pressure are continuously recorded. The reader should refer to Exhibit 10-10 for an example of this type of recorder mounted in a weir system. Another pressure-based recorder is shown in Exhibit 10-11; it is based on the fact that changes in water surface elevation will cause increased or decreased resistance to air escaping from an immersed bubbler tube. A pressure-sensitive translator drives the recording chart.

Stilling wells are specially designed reservoirs used to dampen the effects from surface variations or ripples in the main channel, thus allowing for a more stable and steady surface-level measurement. Such wells are especially desirable if float-type water level recorders are used. Several requirements must be met when stilling wells are used:

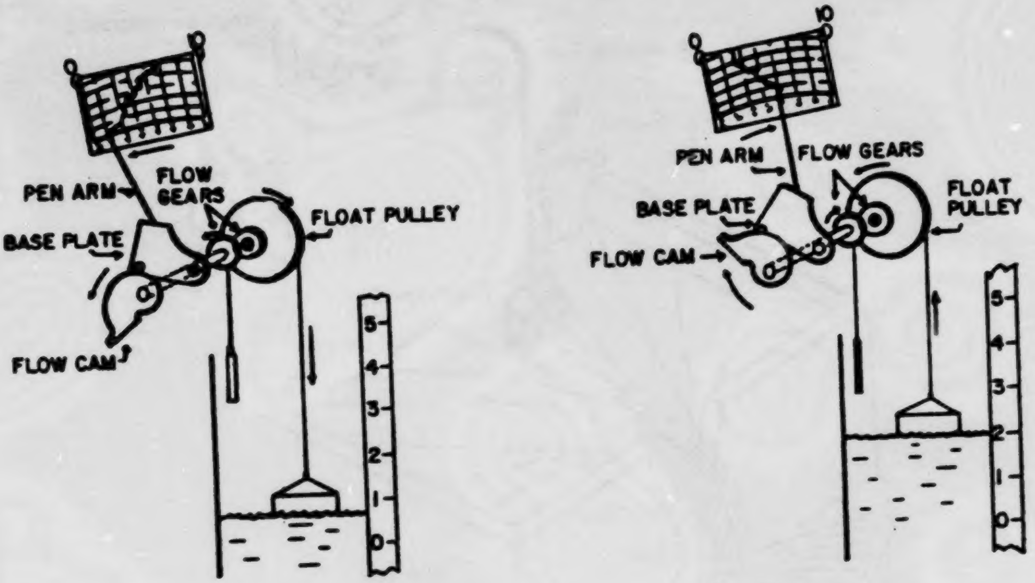
- They must be high enough to cover the entire expected range of surface levels. The well should be long enough that its bottom is at least 0.3 m (1.0 feet) below the minimum stage expected.
- They should be as vertical as possible, so that the float wire or tape can move vertically with no drag or interference.
- Intake pipes or holes should be large enough to make sure that water levels in the well do not lag the rise or fall of levels in the stream.
- They must have provisions to clean out and remove silt.
- If used in freezing weather, they should be provided with a means for heating the devices unless wells can be protected by surrounding ground and a subfloor.
- Stilling wells should have sealed bottoms to avoid seepage if they are installed into streambanks.

**Applicability:** Calibrated water stage gauges are widely applicable to almost any flow measurement problem. Custom-made gauges can even be calibrated to read cfs or $m^3$/sec directly if all other conditions besides surface elevation can be kept constant. This calibration is especially true for flumes and weirs where cross-sectional areas are fixed.

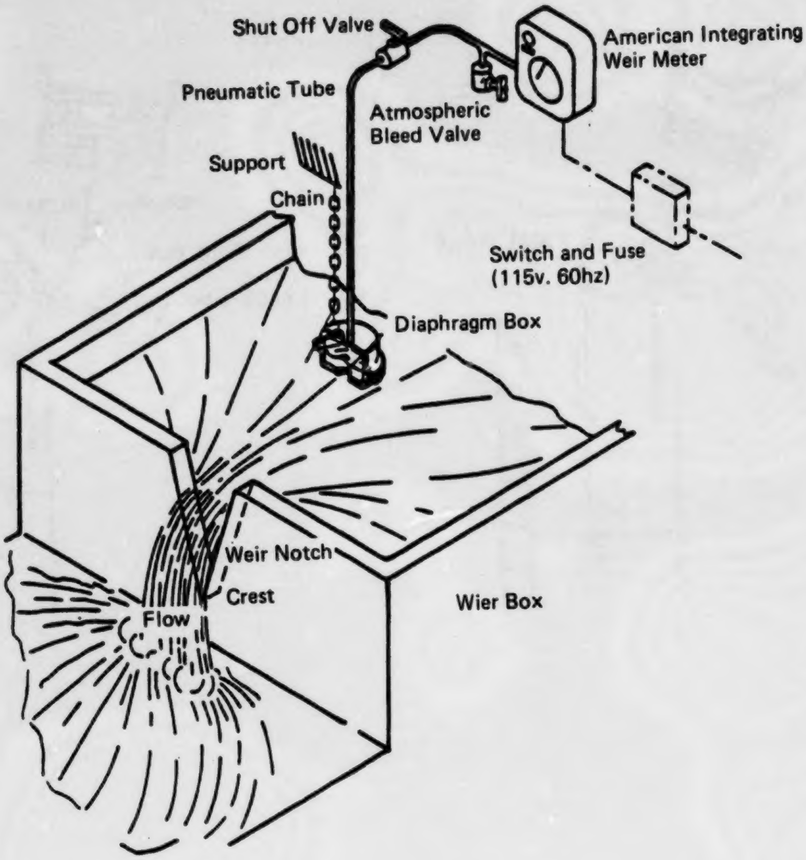
Automatic recorders find their widest use where readings must be made continuously and where staffing is not available around the clock. These recorders are relatively uncommon in site survey work because there are few occasions where continuous measurements are essential. Even flow readings for nearby streams or rivers are rarely made on a continuous basis. However, the need may arise for special application at certain sites, especially if ongoing remedial work is being done.

Stilling wells are beneficial for all flow measuring stations where multiple readings at a weir or flume must be made. These wells are essential at any site where continuous recorders are installed. Because stilling wells are isolated from the main flow by a small-diameter inlet, waves and surges in the main flow will not appear in the well. But the well must be able to accurately reflect all steady fluctuations in the main channel. The well may be made of concrete, wood, ceramic pipe, or metal pipe; it must have a solid bottom; and, except for the inlet, it must be water tight. The stilling well inlet should be located at the desired head measuring point in the primary flow measurement device (weir, flume, orifice). The inlet area should be large enough to quickly reflect changes in the stream, but small enough to provide effective damping of surges. Suggested sizes are as follows:

## Exhibit 10-9
## FLOATING WATER ELEVATION MEASURING DEVICE

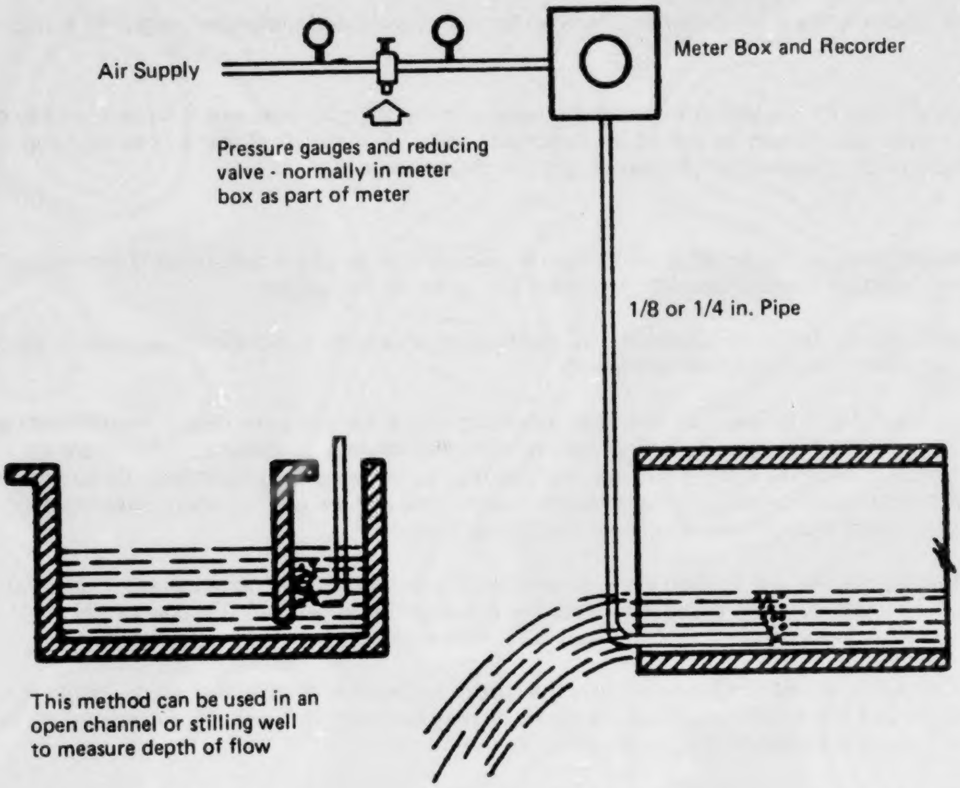

PEN ARM
FLOW GEARS
FLOAT PULLEY
BASE PLATE
FLOW CAM
5
4
3
2
1
0
10
PEN ARM
FLOW GEARS
FLOAT PULLEY
BASE PLATE
FLOW CAM
5
4
3
2
1
0

## Exhibit 10-10
## PRESSURE SENSOR


Shut Off Valve
American Integrating
Weir Meter
Pneumatic Tube
Atmospheric
Bleed Valve
Support
Chain
Switch and Fuse
(115v. 60hz)
Diaphragm Box
Weir Notch
Crest
Wier Box
Flow

## Exhibit 10-11
## AIR BUBBLER FOR MEASURING WATER DEPTH

An air bubbler will measure water depth in pipes and channels. The recorder gauges for the bubbler must be selected for the depth of flow because of low air back-pressure.


Air Supply
Meter Box and Recorder
Pressure gauges and reducing valve - normally in meter box as part of meter
1/8 or 1/4 in. Pipe

This method can be used in an open channel or stilling well to measure depth of flow

If the well is of 6-inch diameter, the inlet should be 3/8-inch diameter.

If the well is of 12-inch diameter, the inlet should be 1/2-inch diameter.

If the well is of 24-inch diameter, the inlet should be 3/4-inch diameter

If the well if of 30-inch diameter, the inlet should be 1-inch diameter.

If the well is of 36-inch diameter, the inlet should be 1-1/4-inch diameter.

USGS recommends at least 18-inch diameters for stilling wells, and prefers to use a 2- to 4-inch intake line.

Selecting a site for the stilling well partially depends on locating an area where stream velocity cross-sectional measurements can be carried out accurately under all variations of stage. The following criteria are generally used, at least in part, for selecting a site for a stilling well.

- A fairly straight section of stream length should be chosen where turbulence is minimal and flow maintains, as much as possible, a uniform flow under varying stages.
- This section should be accessible to a stable channel or control and should be where a stage discharge relationship can be determined.
- An area should be selected that is proximate to where the cross-sectional measurements will be made, possibly at some sort of permanent control structure (e.g., either a bridge where abutments contain the stream width with increasing stages or an underwater rocky ledge). To be avoided are undercut banks or areas where overland flooding will occur easily, or where streambed scour or streambank erosion may occur over the study period.
- The site should be a position in the stream that is away from strong current areas, but where water will be available to the stilling well under low flow conditions. A location should be chosen that will also afford some protection to the installation from strong currents during flood events.
- The site should be at a location where the type of sediment is sand, gravel, consolidated clay, or a mixture of these materials, since the substrate may be required to partially support the installation and to resist settling or tilting of the structure.
- An area of low susceptibility to vandalism should be chosen.

For details on installation and maintenance of stilling wells, the reader should refer to USDI, 1965 and 1974; USGS, 1982; ISCO, 1985; and Stevens, 1978.

### 10.1.5.3 Methods and Applications: Alternative Flow Measurements

At times none of the foregoing flow measurements are applicable to the site-specific problem, so other methods must be investigated. Some of the possibilities are briefly discussed below, but readers will need to refer to other publications or manufacturers' instruction manuals for more details.

**Pitot Tubes:** Although Pitot tubes are usually associated with flow measurements in closed pipes, they can also be used to measure flow velocities in open channels. The principle is illustrated in Exhibit 10-12, where the difference in pressure between an upstream reading and a downstream reading is directly related to flow velocity, at the point of measurement. Pitot tubes are available commercially, and manufacturer's specifications should be consulted before use.

**Applicability:** Pitot tubes should be used where velocities are high enough to generate readable differences in pressure. They are very inaccurate at low velocities, less than 1 fps. Measurements are best made when the upstream straight section is 15 to 20 times the channel width. Pitot tubes are not reliable for streams carrying high concentrations of suspended matter because the tube inlet plugs easily, giving inaccurate pressure readings. The general formula for calculating discharge rates using Pitot tubes is $Q = AV$ where $Q$ is flow in cfs, $A$ is cross-sectional area of separate subsections of the channel in ft$^2$, and $V$ is flow velocity in ft/sec. Further, $V$ is calculated from

$$V = \left[ 2g \frac{(P_2 - P_1)}{d} \right]^{0.5}$$

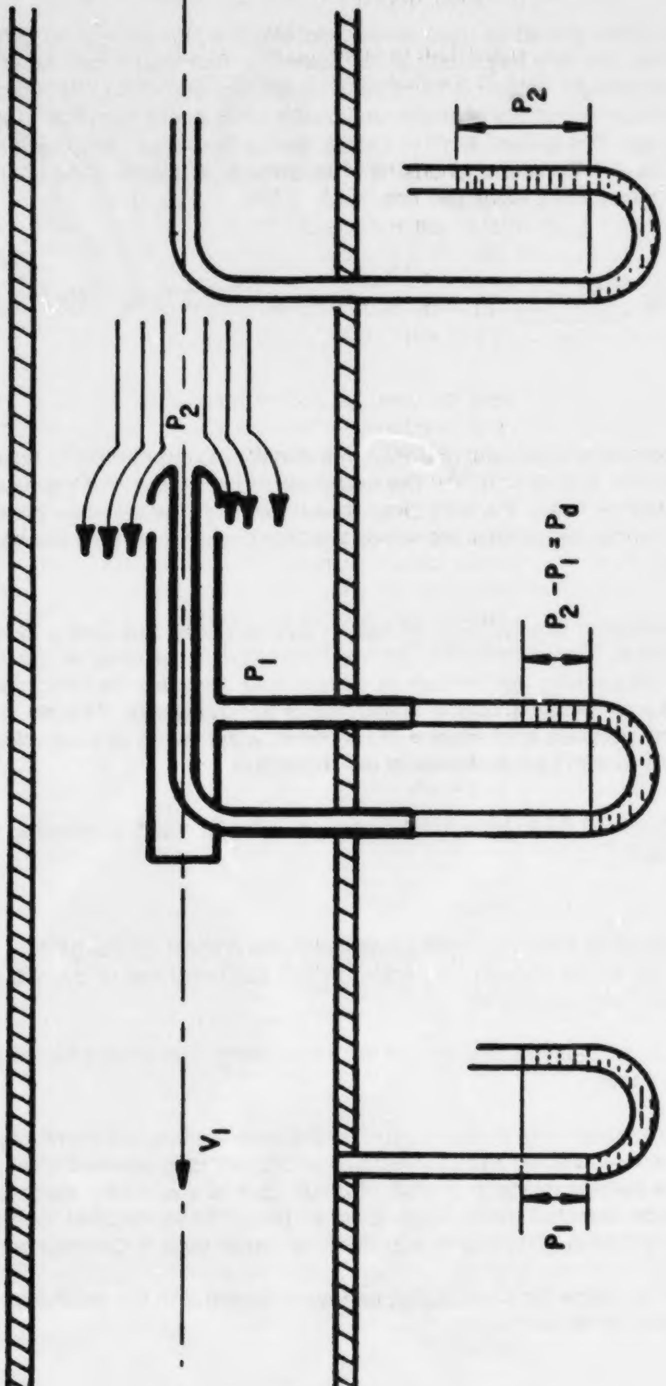
, where $g = 32.2$ ft/sec , $P_2 - P_1$ is the change in pressure in lb/ft$^2$, and $d$ is 62.4, the density of water in lb/ft$^3$. Substituting values for the two constants gives $V = 1.02\,(P_2 - P_1)^{0.5}$. The reader should note that $P_2 - P_1$ is a pressure difference, and not a measure of depth or head. For very small differences in $P$, the equation becomes meaningless. The individual subsections' discharge rates are added together to define the total discharge rate for the entire cross-sectional area.

**Salt and Dye Solutions:** The addition of salt or dye solutions provides a means for estimating volumetric flow rates where channel geometry or inaccessibility render other methods useless. These techniques depend on determining the amount of dilution that a known concentration of a salt or dye receives as it mixes with a much larger volume of salt-free or dye-free water. As a result, the method does not rely on accurate measurements of channel cross sections, water levels, or even velocity. The following general conditions are relevant to successful use of this technique.

(The reader should refer to USDA, 1965; USGS, 1982; and Turner, 1976, for detailed information on salt or dye dilution techniques.)

- The salt or dye used as a tracer should be absent in the original discharge flow, or, if salt or dye is present, it must be of low enough concentration that additional salt or dye will yield a mixed concentration at least five times higher.
- The concentration and the injection rate of the tracer being added must be known. There are two ways to add the tracer:
    - At a constant rate so that downstream concentrations will eventually become constant (best for low flows and inexpensive tracers; has long injection time).
    - As a sudden injection or slug of tracer so that a relatively sharp peak concentration can be detected downstream (best for higher flows; requires long sampling time and many individual measurements to make certain peak is detected and quantified).
- The tracer must be stable both in solution and upon mixing with the discharge. It must not react with any chemicals in the discharge.

## Exhibit 10-12
## PITOT TUBE MEASURES VELOCITY HEAD


$P_2$
$P_2$
$P_1$
$P_2 - P_1 = P_d$
$V_1$
$P_1$

- There must be sufficient mixing in the following stream to ensure that the tracer is evenly distributed on addition. The injection point should be far enough upstream to allow for turbulent mixing before the first measuring point.

- Sufficient injection time must be provided to allow downstream samples to reach a concentration plateau or reach a peak concentration, depending on which injection method is used.

Suitable tracers include sodium, potassium or lithium chloride, fluorescein, and Rhodamine WT dyes. Ideally, concentrations are determined in the field to assure that the downstream concentration plateau was reached and sustained.

**Applicability:** Salt and dye tracer methods have wide application since they do not rely on channel geometry or the ability to measure velocities accurately. These methods do rely heavily on analyzing chemicals, careful metering of concentrated salt and dye solutions, and being able to accurately determine when tracers have reached a point far enough downstream to ensure complete mixing. Wide streams will necessitate the collection of lateral samples for inclusion in the calculations. To guarantee low backgrounds and the absence of materials that may react with the added salt or absorb the dyes, the natural discharge must be analyzed before choice of salt or dye can be made.

**Radioisotopes:** Radioisotopes may be used as tracers instead of the salts and dyes discussed above. Geiger or scintillation counters are used to determine background, concentrated injection solution, and downstream levels of the radioisotopes added. Since radioactivity measurements are made on other samples from hazardous waste sites, this flow measurement technique can be more easily practiced than standard salt / dye tracer methods. The principles, procedures, and methods of calculating flowrates are the same as for other tracers. The radioisotopes will give positive indications when downstream sampling should commence, simplifying the sample collection task. Results are obtained in short order, since analytical equipment and procedures need not be used. The major problem is the necessity for special handling of the radioactive material to prevent exposure to the users and others at the site. Special licenses are required prior to use, and considerable recordkeeping and documentation must be maintained.

**Applicability:** This procedure applies to all situations where salt and dye tracer methods apply. The only exception that could occur would involve a site where background radioactivity is high enough to affect the accuracy of the count. The radioisotopes chosen must have a high detectability range and a low decay rate. The discharge formula for this method is $Q = FA/N$ where $Q$ is the flowrate, $F$ is a calibration factor for the probe and the counting system (see the manufacturer's instructions), $A$ is the total amount of radioactivity injected, and $N$ is the total count downstream.

**Acoustic Flow Meters:** Portable velocity meters, operating on the Doppler principle, have been successfully used to measure flow passing through closed pipes. Use had been limited to situations where bubbles or particles were evenly distributed through the flowing stream, since the meter transmits an ultrasonic pulse that is reflected by the bubbles or particles. Under ideal conditions, a Doppler shift occurs and is directly related to the flow velocity. The meter translates this reading directly into velocity in feet/sec. The pipe cross-sectional area is then multiplied by velocity to obtain discharge rate (U.S. EPA, 1984). Recently, more sensitive meters have been developed for use in situations where the water is relatively free of particles.

**Applicability:** In theory, this instrument is applicable to flow measurements in closed pipe, but in practice many conditions have to be met to ensure reliable readings. The user must be careful to follow all instructions for the particular instrument. All conditions specified for use must be met. Generally, all measurements depend on the flowing stream's ability to transmit sound, on the presence of evenly distributed bubbles or small particles, and on the nonlaminar, turbulent flow of the water at the point of measurement. The user should refer to the instruction manual for the selected instrument before committing it to service.

**Slope-Area Methods:** In situations where installation of a weir or flume is impractical, but the cross-sectional area and approximate slope of the channel are known, the Manning formula provides reasonable estimates of flow velocity. Then the discharge flow rate is readily obtained by multiplying that velocity by the cross-sectional area of the channel at the appropriate water level. No equipment or measuring device is necessary other than a means for estimating water surface level in the channel. Tables are used to simplify the calculation, or the basic Manning equation may be solved directly (USGS, 1982; USDA, 1974; King, 1976; and Davis and Sorenson, 1969).

**Applicability:** The slope-area method is most useful when relatively few measurements are to be made—too few to justify installation of permanent measurement equipment. The primary weakness in the method is the fact that the slope of the hydraulic gradient is not always known, nor is it easy to estimate. Another factor that seriously reduces the accuracy of the method is the need to estimate a roughness coefficient for the channel surface. Because of the difficulties in assigning values to these two factors, the slope-area method is subject to a 20 percent error rate, even when carefully practiced, and a much wider potential error if estimated slopes or roughness coefficients are estimated inaccurately. The basic Manning formula expresses velocity as

$$V = \left[\frac{1.486}{n}\right] R^{2/3} S^{1/2}, \text{ where}$$

$V$ is average velocity in feet/sec, $n$ is the roughness coefficient, $S$ is the slope of the hydraulic gradient, and $R$ is the hydraulic radius in feet. $R$, in turn, is calculated by dividing $A$, the cross-sectional area by $P$, the wetted perimeter (that portion of the channel boundary that is under water).

Roughness coefficients, $n$, are listed in *Water Measurement Manual* by the Bureau of Reclamation for most materials of channel construction. Ranges are given because the coefficients tend to increase with time as a result of erosion, deposition of solids, and corrosion. For additional information on assessing appropriate roughness coefficients, the reader should refer to USGS Water Supply Paper 1849.

### 10.1.6 Region-Specific Variances

In general, site-specific conditions and project requirements will strongly influence the selection of flow-measurement methods. However, regional preferences may occur in method selection when past experience levels are considered. Region IV requires that all sampling and flow measurement events comply with the procedures described in the "Engineering Support Branch Standard Operating Procedures and Quality Assurance Manual" (ESBSOPQAM) dated 2 April 1986 and prepared by the Environmental Services Divison of Region IV. Other similar region-specific variances may evolve as site work progresses and methods are revised or newly published. The reader should contact the EPA RPM for the most up-to-date information on revised methods or variances. Changes in variances will be included in Revision 01 of this compendium.

## 10.1.7 Information Sources

American Society for Testing and Materials. *Manual on Water.* 4th ed. Special Technical Publication 442A. Philadelphia, Pennsylvania: ASTM. 1978.

Davis, C.V., and K.E. Sorenson. *Handbook of Applied Hydraulics.* 3rd ed. New York, New York: McGraw-Hill. 1969.

Fair, G.M., et al. *Water Supply and Wastewater Removal.* New York, New York: John Wiley and Sons, Inc. 1966.

Instrumentation Specialists Company. *ISCO Open Channel Flow Measurement Handbook.* 2nd ed. Lincoln, Nebraska: ISCO. 1985.

King, H.W., and E.F. Brater. *Handbook of Hydraulics.* 6th ed. New York, New York: McGraw-Hill. 1976.

Lythin, J.N. *Drainage Engineering.* Huntington, New York: R.E. Krieger Publishing Co. 1973.

Marsh-McBirney, Inc. *Instruction Manual, Model 201 Portable Water Current Meter.* Gaithersburg, Maryland: Marsh- McBirney, Inc. Undated.

Ohio River Valley Water Sanitation Commission. *Planning and Making Industrial Waste Surveys*. Cincinnati, Ohio: ORSANCO. 1952.

Stevens. *Stevens Water Resource Data Book.* 3rd ed. Beaverton, Oregon: Lenpold-Stevens, Inc. 1978.

Turner. "Fluorometric Facts, Flow Measurements." Monograph. Mountain View, California: Turner Designs Company. 1976.

U.S. Department of Interior, 1965a. "Discharge Measurements at Gaging Stations." *Hydraulic Measurement and Computations.* Book I, Chapter 11. Washington, D.C.: USDA, Geological Survey. 1965.

U.S. Department of Interior, 1965b. "Measurement of Discharge by Dye Dilution Methods." *Hydraulic Measurement and Computations.* Book I, Chapter 14. Washington, D.C.: Geological Survey. 1965.

U.S. Department of Interior. *Water Measurement Manual.* 2nd ed. Revised. Washington, D.C.: USDA. 1974.

U.S. Department of Interior. *National Handbook of Recommended Methods for Water-Data Acquisition.* Reston, Virginia: USDA, OWDC, Geological Survey. 1977.

U.S. Department of Interior. *Measurement and Computations of Streamflow: Volumes 1 and 2.* Geological Survey Water- Supply Paper 2175. Washington, D.C.: USDA. 1982.

U.S. Environmental Protection Agency. *ESB Standard Operating Procedures Quality Assurance Manual.* 1986.

U.S. Environmental Protection Agency. *Handbook for Monitoring Industrial Wastewater.* Washington, D.C.: U.S. EPA. 1979.

U.S. Environmental Protection Agency. *NPDES Compliance Inspection Manual.* Washington, D.C.: U.S. EPA. 1984.

## 10.2 SAMPLING TECHNIQUES

### 10.2.1 Scope and Purpose

This subsection provides general guidance for the collection of surface water, sediment samples, and sludge at hazardous waste sites. The primary objective of any sampling program is the acquisition of samples representative of the source under investigation. Such samples must be suitable for subsequent analysis to enable identification of the types and amounts of pollutants present. Information derived from sampling often forms the basis for litigation and development of remedial action, so all sampling programs must be conducted in a manner that will stand the scrutiny of the court and the public.

### 10.2.2 Definitions

**Sampling**
The physical collection of a representative portion of the population, universe, or environment.

**Environmental Samples**
Usually offsite samples with mid- or low-contaminant concentrations, such as streams, ditches, ponds, soils, and sediments, that are collected at some distance from direct sources of contaminants. Most surface waters are environmental samples.

**Grab Samples**
Discrete aliquots representing a specific location at a given point in time. The sample is collected all at once and at only one particular point in the sample medium.

**Composite Samples**
Nondiscrete samples composed of more than one specific aliquot collected at various locations or at different points in time. Analyzing this type of sample produces an average value for the locations or time period covered by sampling.

**Surface Water Samples**
Samples of water collected from streams, ponds, rivers, lakes, or other impoundments open to the atmosphere. Surface waters flow over or rest on the land.

**Sample Blanks**
Samples of deionized or distilled water, rinsed collection devices or containers, sampling media, etc., that are handled in the same manner as the unknown sample and are subsequently analyzed to identify possible sources of contamination during collection, preservation, shipping, or handling.

**Sediments**
Particles derived from rocks or biological materials that have been transported by a fluid. Sediments include solid matter (sludges) suspended in or settled from water.

**Sampling Plan**

A detailed, site-specific plan that covers all sampling objectives and strategy for a given site. The plan describes methods and equipment used, locations, number and type of samples, safety requirements, transportation and shipping instructions, scheduling, and any other site-related sampling requirements. The reader should refer to Section 4 for details.

### 10.2.3 Applicability

This subsection describes general methods for the physical sampling of surface waters, sludge, and sediments. In most cases, such samples will be low- or medium-hazard wastes, rather than the more concentrated high-hazard wastes collected from drums or storage facilities. The individual site sampling plan will always define the requirements for each sampling program. The reader should refer to Section 4 for details.

The following procedures apply to surface water (streams, rivers, surface impoundments) and sediments (sludges, stream bottoms, solids settled out of water).

### 10.2.4 Responsibilities

Site Managers are responsible for identifying sampling team personnel, assuring that each team member's responsibilities are assigned and understood, ensuring that the project-specific sampling procedures are followed, maintaining chain-of-custody records, and determining that all sampling documents have been completed properly and are accounted for.

Field personnel performing sampling are responsible for properly collecting samples, initiating chain-of-custody forms (see Section 4), monitoring traffic reports, and over seeing the necessary sample documents, as required.

The sampling and analysis coordinator, equipment manager, or the EPA's Sample Management Office authorized requester is responsible for arranging the sample bottle deliveries and coordinating the activities of the field personnel and the Sample Management Office.

### 10.2.5 Records

The various documents, forms, labels, and tags that sampling teams will use in the field have been standardized and are described in detail in Sections 4 and 17. These include field logbooks, sample log sheets, sample labels, sample identification tags, traffic reports (organic, inorganic, and high hazard), custody seals, and chain-of-custody forms. Other forms are not usually standardized (e.g., sample shipping documents that may vary according to the shipping company's requirements or photographic records that necessarily must vary from site to site).

## 10.2.6 Sampling Procedures

### 10.2.6.1 General Considerations

Regardless of the sampling methods or equipment selected, there are several general procedures that are applicable to the collection of all surface water, sludge, or sediment samples. These procedures include the following:

- Before commencing collection of samples, thoroughly evaluate the site. Observe the number and location of sample points, landmarks, references, and routes of access or escape.
- Record pertinent observations. Include a sketch, where appropriate, identifying sample locations.
- Prepare all sampling equipment and sample containers prior to entering site. Provide protective wrapping to minimize contamination.
- Place sample containers on flat, stable surfaces for receiving samples. Use sorbent materials to control spills, if any.
- Plan to collect samples first from those areas that are suspected of being the least contaminated so that areas of suspected contamination are collected last, thus minimizing the risk of cross contamination.
- Collect samples and securely close containers as quickly as feasible. Where possible, make field observations (pH, temperature, conductivity) at the source rather than in containers.
- Follow the sampling plan in every detail. Document all steps in the sampling procedures.
- For potentially hazardous samples, dispose of sampling gear as determined in the sampling plan, or carry it back to the contamination reduction corridor for decontamination and cleaning in a plastic bag.
- For potentially hazardous samples, deliver the sample containers and equipment to the decontamination station for cleaning prior to further handling.
- Always be attentive to the potential hazards posed by the sampling procedures and the material sampled.

Sampling in the Superfund program is closely guided by many EPA documents that originate in several offices. Guidance documents are listed in the subsection on information sources.

### 10.2.6.2 Methods and Applications: Surface Water

Because each hazardous waste site will contain a variety of waste substances, a variety of sampling equipment and techniques will be necessary. By following the procedures out lined in this compendium, the degree of uniformity necessary for defining characteristics of hazardous waste sites can be obtained.

**Surface Water Sampling:** Samples from shallow depths can be readily collected by merely submerging the sample container. The container's mouth should be positioned so that it faces upstream, while the sampling personnel are standing down stream so as not to stir up any sediment to contaminate the sample. The method is advantageous when the sample might be significantly altered during transfer from a collection vessel into another container. This is the case with samples collected for oil and grease analysis, since considerable material may adhere to the sample transfer container and, as a result, produce inaccurately low analytical results. Similarly, the transfer of a liquid into a small sample contained for volatile organic analysis, if not done carefully, could result in significant aeration and resultant loss of volatile species. Though simple, representative, and generally free from substantial material disturbances, the act of transferring has significant shortcomings when applied to a hazardous waste, since the external surface of each container would then need to be decontaminated.

In general, the use of a sampling device, either disposable or constructed of a nonreactive material such as glass, stainless steel, or Teflon, is the most prudent method. The device should have a capacity of at least 500 ml, if possibly, to minimize the number of times the liquid must be disturbed, thus reducing agitation of any sediment layers. A 1-liter polypropylene or stainless steel beaker with pour spout and handle works well. Any sampling device may contribute contaminants to a sample. The sampling devices that should be selected are those that will not compromise sample integrity and will give the desired analytical results.

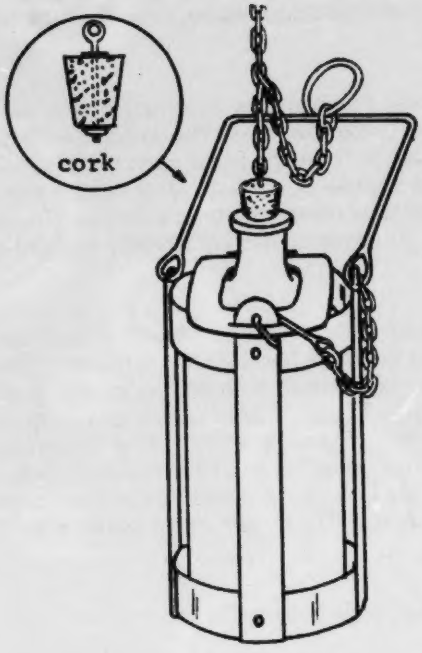
Collecting a representative sample from a larger body of surface water is difficult but not impossible. Samples should be collected near the shore unless boats are feasible and permitted. If boats are used, the body of water should be cross sectioned, and samples should be collected at various depths across the water in accordance with the specified sampling plan. For this type of sampling, a weighted-bottle sampler is used to collect samples at any predetermined depth. The sampler (Exhibit 10-13) consists of a glass bottle, a weighted sinker, a bottle stopper, and a line that is used to open the bottle and to lower and raise the sampler during sampling. There are variations of this sampler, as illustrated in ASTM methods D 270 and E 300. This sampler can be either fabricated or purchased. The procedure for use is as follows:

- Assemble the weighted bottle sampler as shown in Exhibit 10-13.
- Gently lower the sampler to the desired depth so as not to remove the stopper prematurely.
- Pull out the stopper with a sharp jerk of the sampler line.
- Allow the bottle to fill completely, as evidenced by the cessation of air bubbles.
- Raise the sampler and cap the bottle.
- Wipe the bottle clean. The bottle can be also be used as the sample container.

Teflon bailers have also been used while feasible for collecting samples in deep bodies of water. Where cross-sectional sampling is not appropriate, near-shore sampling may be done using a pond sampler (refer to Exhibit 10-14).

In this instance, a modification that extends the reach of the sampling technician is most practical. The modification incorporates a telescoping heavy-duty aluminum pole with an adjustable beaker clamp attached to the end. A disposable glass, plastic container, or the actual sample container itself can be fitted into the clamp. In situations where cross contamination is of concern, use of a disposable contained or the actual sample container is always advantageous. The cost of properly cleaning usually outweighs the cost of disposal of otherwise reusable glassware or bottles, especially when the cleanup must be done in the field. The potential contamination of samples for volatile organic analysis by the mere presence of organic solvents necessary for proper field cleaning is usually too great to risk.

## Exhibit 10-13
## WEIGHTED-BOTTLE SAMPLER



1000-ml (1-quart) weighted-bottle catcher

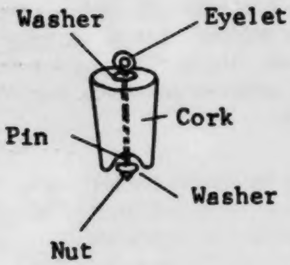
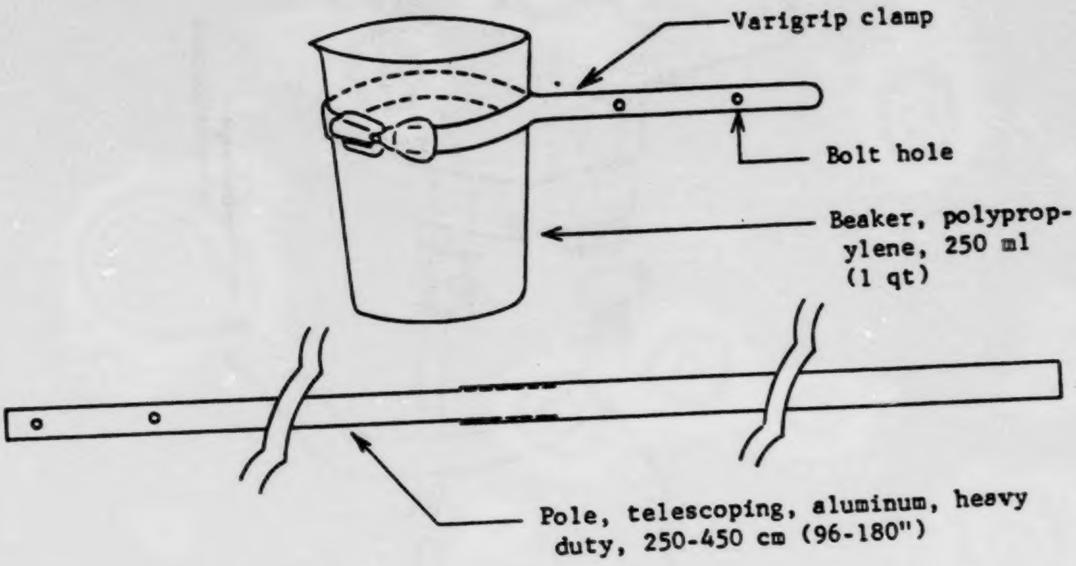
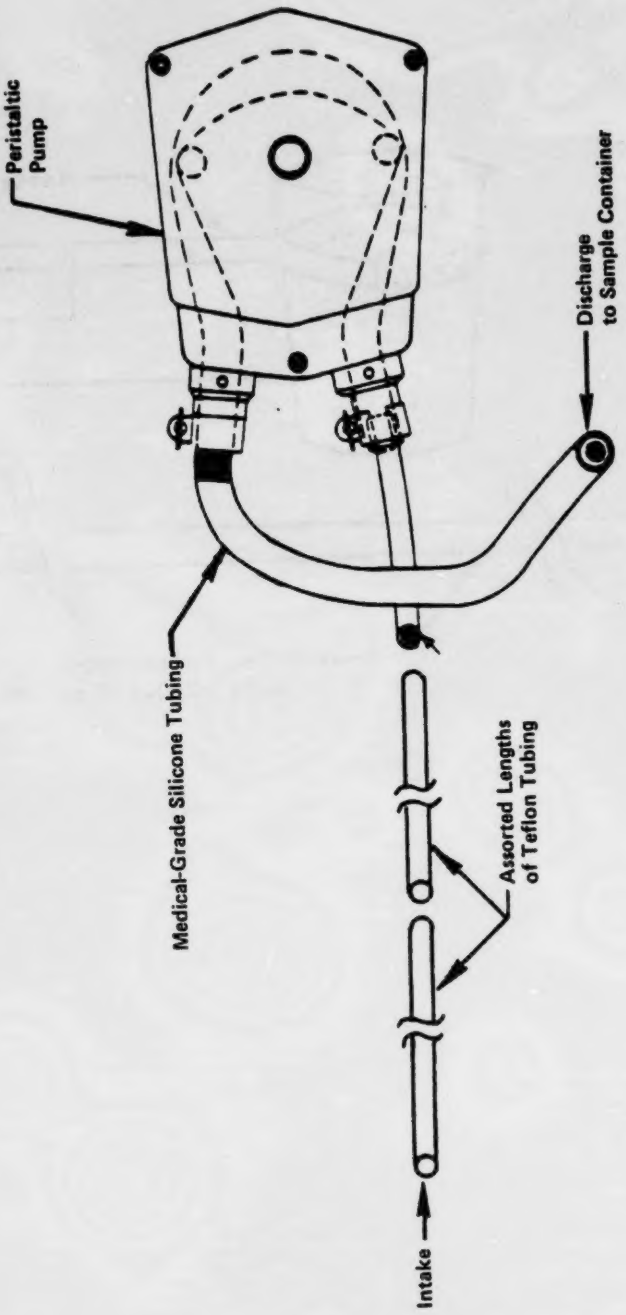

Washer
Eyelet
Cork
Pin
Washer
Nut

Exhibit 10-14

## POND SAMPLER


Varigrip clamp
Bolt hole
Beaker, polypropylene, 250 ml (1 qt)
Pole, telescoping, aluminum, heavy duty, 250-450 cm (96-180")

## Exhibit 10-15
## PERISTALTIC PUMP SAMPLER


Peristaltic Pump
Discharge to Sample Container
Medical-Grade Silicone Tubing
Assorted Lengths of Teflon Tubing
Intake

Another method of extending the reach of sampling efforts is the use of a small peristaltic pump (see Exhibit 10-15). In this method the sample is drawn through heavy-wall Teflon tubing and pumped directly into the sample container. This system allows the operator to reach into the liquid body, sample from depth, or sweep the width of narrow streams.

If medical-grade silicon tubing is used in the peristaltic pump, the system is suitable for sampling almost any parameter including most organics. Some volatile stripping, however, may occur; though the system may have a high flow rate, some material may be lost on the tubing. Therefore, pumping methods should be avoided for sampling volatile organics or oil and grease. Battery-operated pumps of this type are available and can be easily carried by hand or with a shoulder sling. It is necessary in most situations to change both the Teflon suction line and the silicon pump tubing between sample locations to avoid cross contamination. This action requires maintaining a sufficiently large stock of material to avoid having to clean the tubing in the field.

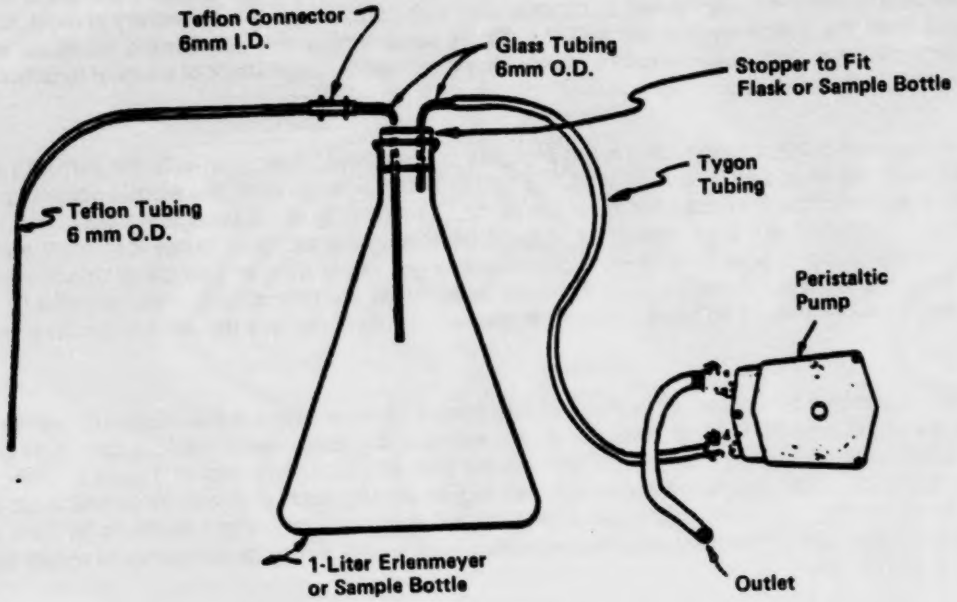
When medical-grade silicon tubing is not available or the analytical requirements are particularly strict, the system can be altered as illustrated in Exhibit 10-16. In this configuration, the sample volume accumulates in the vacuum flask and does not enter the pump. The integrity of the collection system can now be maintained with only the most nonreactive material contacting the sample. Some loss in lift ability will result since the pump is now moving air, a compressible gas rather than an essentially noncompressible liquid. Also, this system cannot be used if volatile compounds are to analyzed. The potential for losing volatile fractions because of reduced pressure in the vacuum flask renders this method unacceptable for use.

It may sometimes be necessary to sample large bodies of water where a near-surface sample will not sufficiently characterize the body as a whole. In this instance, the above-mentioned pump is quite serviceable. It is capable of lifting water from depths in excess (but not much in excess) of 6 meters. It should be noted that this lift ability decreases somewhat with higher density fluids and with increased wear on the silicone pump tubing. Similarly, increases in altitude will decrease the pump's ability to lift from depth. When sampling a liquid stream that exhibits a considerable flowrate, it may be necessary to weight the bottom of the suction line.

Samples from various locations and depths can be composited where investigative goals indicate that it is appropriate; otherwise, separate samples will have to be collected. Approximate sampling points should be identified on a sketch of the water body. The following procedures are used for samples collected using transfer devices:

- Submerge a stainless steel dipper or other suitable device with minimal surface disturbance. Note the approximate depth and location of the sample source (for example, 1 foot up from bottom or just below the surface).
- Allow the device to fill slowly and continously.
- Retrieve the dipper or device from the surface water with minimal disturbance.
- Remove the cap from the sample bottle and slightly tilt the mouth of the bottle below the dipper or device edge.
- Empty the dipper or device slowly, allowing the sample stream to flow gently down the side of the bottle with minimal entry turbulence.
- Continue delivery of the sample until the bottle is almost completely filled. Check all procedures for recommended headspace for expansion.

## Exhibit 10-16
## MODIFIED PERISTALTIC PUMP SAMPLER


Teflon Connector
6mm I.D.
Glass Tubing
6mm O.D.
Stopper to Fit
Flask or Sample Bottle
Tygon
Tubing
Teflon Tubing
6 mm O.D.
Peristaltic
Pump
1-Liter Erlenmeyer
or Sample Bottle
Outlet

- Preserve the sample, if necessary, as per guidelines in sampling plan. In most cases, preservatives should be placed in sample containers before sample collection to avoid over exposure of samples and overfilling of bottles during collection.

- Check that a Teflon liner is present in the cap if required. Secure the cap tightly. Tape cap to bottle; then date and initial the tape.

- Label the sample bottle with an appropriate sample tag. Be sure to label the tag carefully and clearly, addressing all the categories or parameters. Record the information in the field logbook and complete the chain-of-custody form.

- Place the properly labeled sample bottle in an appropriate carrying container. Water samples for low- or medium-level organics analysis and low-level inorganics must be shipped cooled to 4°C with ice. No ice is to be used in shipping inorganic low-level soil samples; medium / high-level water samples, organic high-level water or soil samples, or dioxin samples. Ice is not required in shipping soil samples, but ice may be used at the option of the sampler. All cyanide samples, however, must be shipped cooled to 4°C. Use a custody seal on the shipping package and make certain that traffic report forms are properly filled out.

- Dismantle the sampler, wipe the parts with terry towels or rags, and store them in plastic bags for subsequent disposal. Follow all instructions for proper decontamination of equipment and personnel.

The reader should refer to Sections 4, 5, and 6 for additional details.

For samples collected using peristaltic pumps:

- Install clean, medical-grade silicone tubing in the pump head, as per the manufacturer's instructions. Allow sufficient tubing on the discharge side to facilitate convenient dispensation of liquid into sample bottles but only enough on the suction end for attachment to the intake line. This practice will minimize sample contact with the silicone pump tubing. (Some types of thinner Teflon tubing may be used.)

- Select the length of suction intake tubing necessary to reach the required sample depth and attach the tubing to intake side of pump tubing. Heavy-wall Teflon of a diameter equal to the required pump tubing will suit most applications. (A heavier wall will allow for a slightly greater lateral reach.)

- If possible, allow several liters of sample to pass through the system before actual sample collection. Collect this purge volume, and then return it to source after the sample aliquot has been collected.

- Fill necessary sample bottles by allowing pump discharge to flow gently down the side of bottle with minimal entry turbulence. Cap each bottle as filled.

- Preserve the sample, if necessary, as per guidelines in sampling plans. In most cases, preservatives should be placed in sample containers before sample collection to avoid overexposure of samples and overfilling of bottles during collection.

- Check that a Teflon liner is present in the cap, if required. Secure the cap tightly. Tape cap to bottle; then date and initial the tape.

- Label the sample bottle with an appropriate tag. Be sure to complete the tag with all necessary information. Record the information in the field logbook, and complete the chain-of-custody documents.

- Place the properly labeled sample bottle in an appropriate carrying container. Water samples for low- or medium-level organics analysis and low-level inorganics must be shipped cooled to 4°C with ice. No ice is to be used in shipping inorganic low-level soil samples; medium/ high-level water samples, organic high-level water or soil samples, or dioxin samples. Ice is not required in shipping soil samples, but ice may be used at the option of the sampler. All cyanide samples, however, must be shipped cooled to 4°C. Use a custody seal on the shipping package and make certain that traffic report forms are properly filled out.

- Allow system to drain thoroughly; then disassemble. Wipe all parts with terry towels or rags, and store them in plastic bags for subsequent cleaning. Store all used towels or rags in garbage bags for subsequent disposal. Follow all instructions for proper decontamination of equipment and personnel.

The reader should refer to Sections 4, 5, and 6 for additional details.

At times it is most convenient to collect surface water samples at the flow measuring device (e.g., a weir, stream, or discharge pipe). Good representative samples can usually be collected because such flows have been mixed well. Sampling personnel have been trained to seek out the best locations for collecting representative samples. Requirements are spelled out in the site sampling plans, and the need for deviation from the plans occurs only rarely. There is no substitute for experience when it comes to locating "ideal" sampling points and collecting good samples.

### 10.2.6.3 Methods and Applications: Sediments and Sludges

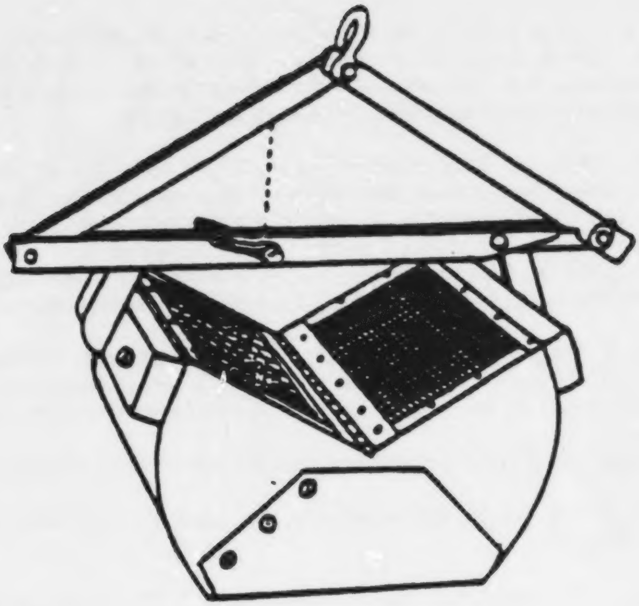
Many of the same constraints that apply to surface water sampling also relate to the collection of sediments and sludges. Sediments are examined to measure whether contaminants are concentrating along stream bottoms, creating hot spots that may have high concentrations of heavy metals, pesticides, or low-solubility organic matter. Sediments may be watery, with relatively little difference in density from water, or they may be compacted semi-solids where water is a minor fraction of the mass. Because of such difference, a variety of sampling methods and equipment may be necessary.

If the sediment has the potential for being considered a hazardous material, disposable sampling equipment should be considered. For watery sludges from stream bottoms near shore, the pond sampler shown as Exhibit 10-14 can be used, since the plastic beaker can be disposed of, if the sampling plan so ordains. Other devices could include plastic pails or ladles for scooping up sediments from shallow water. The user should allow time for settling to occur, then decant the water off the top of the sediment before transferring samples to their containers. The user should sample only with plastic beakers, pails, or ladles where sample integrity of organics will not be compromised.

The semi-solid sediments near shore or above the water line are most easily collected using simple tools (e.g., polypropylene scoops, trowels, or dippers). Other alternatives for small semi-solid sediments include wooden tongue depressors or stainless steel tablespoons.

If stream-bottom samples of sediment are necessary, vertical-pipe or core samplers are used and can be driven into stream beds to any selected depth. During retrieval, samples are retained inside the cylinder by a partial vacuum formed above the sample and/or by a retainer at the lower end. For compacted sediment, sampling triers or waste pile samplers may be used as long as sample points are above the water

## Exhibit 10-17
## PONAR GRAB SAMPLER



surface or in very shallow water. If deep water samples from large streams or lakes are specified, specialized samplers (e.g., Eckman or Ponar dredges) are used.

No matter what equipment is used, the following general conditions apply:

- Collect at least three small, equal-sized samples from several points along the sludge or sediment deposition area. If possible, mark the location with a numbered stake, and locate sample points on a sketch of the site. Deposit sample portions in a clean, 1/2-gallon wide-mouth jar. Carefully stir portions together into one composite.
- Sediments from large streams, lakes, and the like may be taken with Eckman or Ponar dredges from a boat. Refer to Exhibit 10-17 for an example of a Ponar grab sampler. Ponar grab samplers are more applicable to a wide range of sediments and sludges because they penetrate deeper and seal better than spring-activated types (e.g., Eckman dredges).
- Streams and lakes will likely demonstrate significant variations in sediment composition with respect to distance from inflows, discharges,or other disturbances. It is important, therefore, to document exact sampling location by means of triangulation with stable references on the banks of the stream or lake. In addition, the presence of rocks, debris, or organic material may complicate sampling and preclude the use of, or require modification to, some devices. Sampling of sediments should, therefore, be conducted to reflect these and other variants.
- Transfer 100 to 200 grams of the composite sludges or sediments from the 1/2-gallon jar to a 250-ml sample bottle. Attach identification label number and tag. Record all necessary information in the field logbook and on the sample log sheet. Return unused sample to its source.
- Store the sampler and jars in a plastic bag until decontamination or disposal.
- Tape the lid on the sample bottle securely, and mark the tape with the date and the sample collector's initials.
- Pack the samples for shipping. Attach a custody seal to the shipping package. Make certain that a traffic report and chain-of custody forms are properly filled out and enclosed or attached.

The reader should refer to Sections 4, 5, and 6 for additional details.

Specific sampling equipment for collecting sediment and sludge specimens and procedures for their use are as follows:

**Scoops and Trowels:** This method provides for a simple, quick, and easy means of collecting a disturbed sample of a sludge or sediment.

- Collect the necessary equipment, and clean according to the requirements for the analytical parameters to be measured.
- Sketch the sample area, or note recognizable features for future reference.
- Insert scoop or trowel into material, and remove sample. In the case of sludges exposed to air, it may be desirable to remove the first 1 to 2 cm of material prior to collecting sample.

- If compositing a series of grab samples, use a plastic or stainless steel mixing bowl or Teflon tray for mixing.
- Transfer sample into an appropriate sample bottle with a stainless steel laboratory spoon, scoop, or spatula.
- Check that a Teflon liner is present in cap, if required. Secure the cap tightly. The chemical preservation of solids is generally not recommended. Refrigeration to 4°C is usually the best approach, supplemented by a minimal holding time.
- Label the sample bottle with the appropriate sample tag. Be sure to label the tag carefully and clearly, addressing all the categories or parameters. Complete all chain-of-custody documents, and record in the field logbook.
- Place the properly labeled sample bottle in an appropriate carrying container. Water samples for low- or medium-level organics analysis and low-level inorganics must be shipped cooled to 4°C with ice. No ice is to be used in shipping inorganic low-level soil samples; medium / high-level water samples, organic high-level water or soil samples, or dioxin samples. Ice is not required in shipping soil samples, but ice may be used at the option of the sampler. All cyanide samples, however, must be shipped cooled to 4°C. Use a custody seal on the shipping package and make certain that traffic report forms are properly filled out.

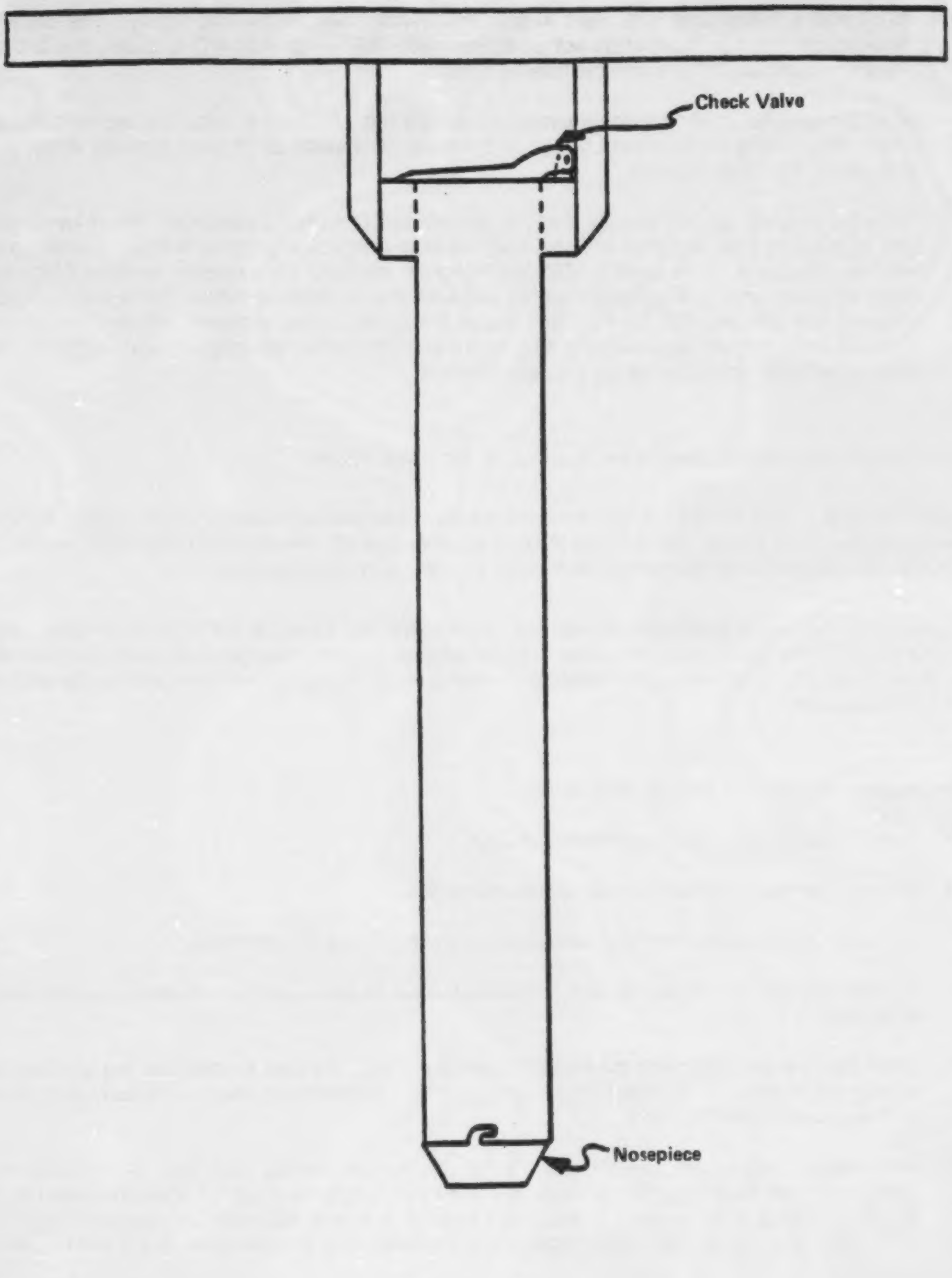
The reader should refer to Sections 4, 5, and 6 for additional details.

**Hand Corers:** (see Exhibit 10-18) Hand corers are applicable to the same situations and materials as the scoop described above. Corers have the further advantage of collecting an undisturbed sample that can profile any stratification in the sample as a result of changes in the deposition.

Some hand corers can be fitted with extension handles that will allow the collection of samples underlying a shallow layer of liquid. Most corers can also be adapted to hold liners generally available in brass or polycarbonate plastic. Care should be taken to choose a material that will not compromise the intended analytical procedures.

- Inspect the cores for proper precleaning.
- Force cores in with smooth continuous motion.
- Twist cores; then withdraw in a single smooth motion.
- Remove nosepiece and withdraw sample into a stainless steel or Teflon tray.
- Transfer sample into an appropriate sample bottle with a stainless steel laboratory spoon, scoop, or spatula.
- Label the sample bottle with the appropriate sample tag. Be sure to label the tag carefully and clearly, addressing all the categories or parameters. Complete all chain-of-custody documents, and record in the field logbook.
- Place the properly labeled sample bottle in an appropriate carrying container. Water samples for low- or medium-level organics analysis and low-level inorganics must be shipped cooled to 4°C with ice. No ice is to be used in shipping inorganic low-level soil samples; medium / high-level water samples, organic high-level water or soil samples, or dioxin samples. Ice is not required in

## Exhibit 10-18
## HAND CORER


Check Valve
Nosepiece

shipping soil samples, but ice may be used at the option of the sampler. All cyanide samples, however, must be shipped cooled to 4°C. Use a custody seal on the shipping package and make certain that traffic report forms are properly filled out.

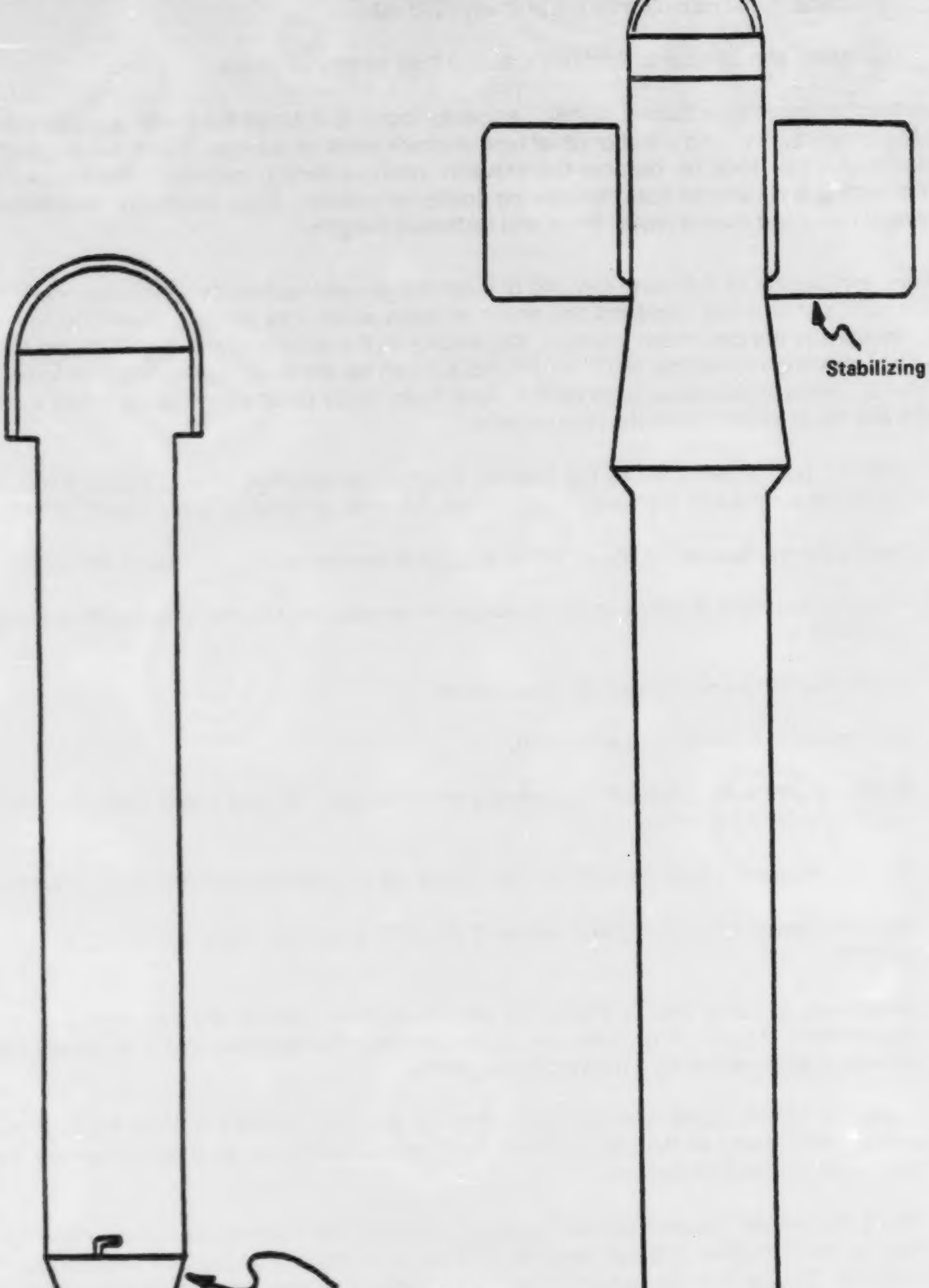
The reader should refer to Sections 4, 5, and 6 for additional details.

**Gravity Corers:** (see Exhibit 10-19). A gravity corer is a metal tube with a replaceable tapered nosepiece on the bottom and a ball or other type of check valve on the top. The check valve allows water to pass through the corer on descent but prevents washout during recovery. The tapered nosepiece facilitates cutting and reduces core disturbance during penetration. Most corers are constructed of brass or steel, and many can accept plastic liners and additional weights.

Corers are capable of collecting samples of most sludges and sediments. The corers collect essentially undisturbed samples that represent the profile of strata which may develop in sediments and sludges during variations in the deposition process. Depending on the density of the substrate and the weight of the cores, penetration to depths of 75 cm (30 inches) can be attained. Care should be exercised when using gravity corers in vessels or lagoons that have liners, since penetration depths could exceed that of substrate and result in damage to the liner material.

- Attach a precleaned corer to the required length of sample line. Solid braided 5 mm (3/16 inch) nylon line is sufficient; 20 mm (3/4 inch) nylon, however, is easier to grasp during hand hoisting.
- Secure the free end of the line to a fixed support to prevent accidental loss of the corer.
- Measure and mark distance to top of sludge on sampler line to determine depth of sludge or sediment coring.
- Allow corer to free fall through liquid to bottom.
- Determine depth of sludge penetration.
- Retrieve corer with a smooth, continuous lifting motion. Do not bump corer because this may result in some sample loss.
- Remove nosepiece from corer, and slide sample out of corer into stainless steel or Teflon pan.
- Transfer sample into appropriate sample bottle with a stainless steel laboratory spoon, scoop, or spatula.
- Check that a Teflon liner is present in cap, if required. Secure the cap tightly. The chemical preservation of solids is generally not recommended. Refrigeration to 4°C is usually the best approach, supplemented by a minimal holding time.
- Label the sample bottle with the appropriate sample tag. Be sure to label the tag carefully and clearly, addressing all the categories or parameters. Complete all chain-of-custody documents, and record in the field logbook.
- Place the properly labeled sample bottle in an appropriate carrying container. Water samples for low- or medium-level organics analysis and low-level inorganics must be shipped cooled to 4°C with ice. No ice is to be used in shipping inorganic low-level soil samples; medium / high-level water samples, organic high-level water or soil samples, or dioxin samples. Ice is not required in shipping soil samples, but ice may be used at the option of the sampler. All cyanide samples, however, must be shipped cooled to 4°C. Use a custody seal on the shipping package and make certain that traffic report forms are properly filled out.
  The reader should refer to Sections 4, 5, and 6 for additional details.

Exhibit 10-19
GRAVITY CORER


Stabilizing Fins
Nosepiece

**Ponar Grab Sampler:** (see Exhibit 10-17) The Ponar grab is a clamshell-type scoop activated by a counter-lever system. The shell is opened, latched in place, and slowly lowered to the bottom. When tension is released on the lowering cable, the latch releases and the lifting action of the cable on the lever system closes the clamshell.

Ponars are capable of sampling most types of sludges and sediments from silts to granular materials. They are available in a "petite" version with a 232-square-centimeter sample area that is light enough to be operated without a winch or crane. Penetration depths will usually not exceed several centimeters. Grab samplers are not capable of collections undisturbed samples. As a result, material in the first centimeter of sludge cannot be separated from that at lower depths. The sampling action of these devices causes agitation currents that may temporarily resuspend some settled solids. This disturbance can be minimized by slowly lowering the sampler the last half-meter and by allowing a very slow contact with the bottom. It is advisable, however, to collect sludge or sediment samples only after all overlying water samples have been obtained. Steps in using Ponar dredges are as follows:

- Attach a precleaned Ponar to the necessary length of sample line. Solid braided 5 mm (3/16 inch) nylon line is usually of sufficient strength; however, 20 mm (3/4 inch) or greater nylon line allows for easier hand hoisting.
- Measure and mark the distance to top of sludge on the sample line. Record depth to top of sludge and depth of sludge penetration.
- Open sampler jaws until latched. From this point on, support the sampler by its lift line, or the sampler will be tripped and the jaws will close.
- Tie free end of sample line to fixed support to prevent accidental loss of sampler.
- Begin lowering the sampler until the proximity mark is reached.
- Slow rate of descent through last meter until contact is felt.
- Allow sample line to slack several centimeters. In strong currents, more slack may be necessary to release mechanism.
- Slowly raise dredge clear of surface.
- Place Ponar into a stainless steel or Teflon tray and open. Lift Ponar clear of the tray, and return Ponar to laboratory for decontamination.
- Collect a suitable aliquot with a stainless steel laboratory spoon or equivalent, and place sample into appropriate sample bottle.
- Label the sample bottle with the appropriate sample tag. Be sure to label the tag carefully and clearly, addressing all the categories or parameters. Complete all chain-of-custody documents and records in the field logbook.
- Place the properly labeled sample bottle in an appropriate carrying container. Water samples for low- or medium-level organics analysis and low-level inorganics must be shipped cooled to 4°C with ice. No ice is to be used in shipping inorganic low-level soil samples; medium / high-level water samples, organic high-level water or soil samples, or dioxin samples. Ice is not required in shipping soil samples, but ice may be used at the option of the sampler. All cyanide samples, however, must be shipped cooled to 4°C. Use a custody seal on the shipping package and make certain that traffic report forms are properly filled out.

The reader should refer to Sections 4, 5, and 6 for additional details.

### 10.2.7 Region-Specific Variations

The reader should refer to Subsection 10.1.6 for discussion. In addition to examples cited there, certain specific procedures may be subject to continuous revisions, so users should contact the EPA RPM for to the most recent procedures advocated by each region. For example, sediment sampling for possible TCDD contamination contains special precautions as outlined in Section 13. Some regions will incorporate these precautions, whereas others will prohibit use of certain equipment. Such variances change from month to month, so a special effort has to be made by SMs and field team leaders to keep current on the various requirements. Revision 01 to this compendium will include updated variances.

### 10.2.8 Information Sources

deVera, E.R., B.P. Simmons, R.D. Stephens, and D.L. Storm. "Samplers and Sampling Procedures for Hazardous Waste Streams." EPA 600/2-80-018. January 1980.

Environmental Monitoring System Laboratory (EMSL), ORD, U.S. Environmental Protection Agency. *Characterization of Hazardous Waste Sites--A Method Manual, Volume II--Available Sampling Methods.* Las Vegas, Nevada 89114. 1983.

Lind, Orent. *Handbook of Common Methods of Limnology.* St. Louis, Missouri: C.V. Mosby Co. 1974.

OWDC, U.S. Geological Survey, U.S. Department of the Interior. *National Handbook of Recommended Methods for Water-Data Acquisition.* Prepared cooperatively by agencies of the U.S. Government. Reston, Virginia. 1977.

Smith, R., and G.V. James. *The Sampling of Bulk Materials.* London: The Royal Society of Chemistry. 1981.

# SECTION 11

# METEOROLOGY AND AIR QUALITY

## 11.1 SCOPE AND PURPOSE

Section 11 describes the meteorological data that are required to make preliminary (screening) assessments of exposure to hazardous air pollutants before site-specific monitoring data are available. Similarly, the meteorological data requirements for conducting analyses of more refined air quality modeling are described in terms of using both representative offsite and site-specific data. The section also identifies procedures for obtaining the appropriate meteorological information both from existing sources and by conducting site-specific monitoring programs.

## 11.1.1 Meteorological Parameters for Screening Model Analyses

### 11.1.1.1 Scope and Purpose

This subsection describes the meteorological data required to make preliminary assessments of exposure to hazardous air pollutants through the use of screening dispersion models. These models are generally used before site-specific monitoring data are available. Screening models purposely over estimate air quality input. This over-estimation is largely a result of the generalization of model inputs and the assumption inherent in the models that certain meteorological conditions, which produce high impacts occur and persist at the site. It is useful to describe the required meteorological parameters, how they are obtained and applied in screening models, and how the results may be used. Such information provides a more complete perspective in determining the possible need for more refined modeling analyses and the associated meteorological data requirements. This subsection provides a general discussion of model selection with more specific guidance provided in the references. Selection of an appropriate model depends on project- and site-specific considerations.

### 11.1.1.2 Definitions

Specific descriptions of the following generic terms are provided in the text.

**Dispersion Model**
A set of algorithms designed to simulate the transport and diffusion of airborne pollutants to obtain estimates of pollutant concentrations at specific receptor locations for specific time periods.

**Hazardous Air Pollutant**
An air pollutant to which no ambient air quality standard applies and that, in the judgment of the Administrator of the U.S. EPA, causes, or contribute to, air pollution that may reasonably be anticipated to result in an increase in mortality or an increase in serious irreversible illness or incapacitating reversible illness.

**Joint Frequency Distribution**
A statistical distribution that lists the frequency of concurrent wind speed, wind direction, and atmospheric stability data by individual wind speed groups, wind direction sectors, and atmospheric stability classes.

**Receptors**

The fixed locations relative to modeled sources at which concentration estimates are predicted.

**Screening Technique**

A relatively simple analysis technique to determine if a given source is likely to pose a threat to air quality. Concentration estimates from screening techniques are conservative.

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. This person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

**Source**

The point or area of origin of hazardous pollutants emitted into the ambient air.

**Source Terms**

The set of information that describes the rates, locations, dimensions, and operational and physical release characteristics of hazardous pollutants emitted into the ambient air.

### 11.1.1.3 Applicability

Screening models are used to provide a conservative estimate of the air quality impact of a specific source or source category (U.S. EPA, 1978, p. 17). Depending on the level of refinement, screening model analyses can also be used to determine: the meteorological conditions that result in maximum short-term and long-term impacts; the potential for exceeding acceptable ambient concentrations; the receptor locations at which maximum ambient levels are predicted to occur (for use if refined modeling is needed); and impacts on sensitive receptors (State and Territorial Air Pollution Program Administrators / Association of Local Air Pollution Control Officials (STAPPA/ALAPCO), 1984, pp. 135-136). The guidance for use of screening models was developed primarily in relation to the evaluation of sources of "criteria" air pollutants (e.g., particulates, sulfur dioxide, and nitrogen dioxide) for which National Ambient Air Quality Standards exist (U.S. EPA, 1981a). The need for equivalent standards for the host of hazardous air pollutants is recognized by federal, state, and local agencies charged with protecting the air quality in their jurisdictions (STAPPA/ALAPCO, 1984).

These currently evolving standards are expressed in terms of a concentration averaged over some period of time. The averaging time depends on the specific health impacts known to be associated with a hazardous substance. The ability of these substances to have an impact on health over the short term (e.g., a 24-hour average) and the long term (e.g., an annual average) creates the need for screening analyses to be performed over these different time scales (STAPPA/ALAPCO, 1984, pp. 132-134). The meteorological input data requirements differ between screening models that produce short-term and long-term concentration estimates. These requirements are discussed in Subsection 11.1.1.6.2.

### 11.1.1.4 Responsibilities

**Project Meteorologist and Air Quality Analyst:** This person is responsible, through coordination with the appropriate regulatory agencies, for selecting appropriate screening methodologies and model(s), selecting representative meteorological data required as model input, performing model calculations, evaluating and reporting results, and maintaining records that document these activities. The execution of air quality models requires the input of source-term data. If they have the requisite engineering skills, project meteorologist and air quality analysts may develop this information; if they do not have this capability, they will need to work closely with the SM.

**Site Manager:** The SM is responsible for the program design and coordination. The project engineer also interacts with the project meteorologist in modeling and monitoring applications, such as source term development.

### 11.1.1.5 Records

Records of the meteorological data selected for use in the screening model analyses must be maintained to validate these data and to evaluate the modeling results. Selection and determination of the representativeness of meteorological parameters should be documented, as well as the selection, application, and results of the model analyses. The level of detail in these records must support the program's quality assurance requirements, which are to be established before making the screening model analyses.

Quality assurance records include those records that furnish documentary evidence of the quality of items and of activities affecting quality. Examples of such records include, but are not limited to, the following: raw data records (e.g., strip charts), data validation findings, equipment maintenance and calibration records, work instructions, work scopes (design control documents), model inputs and outputs, modeling assumptions, and software documentation and verification.

### 11.1.1.6 Procedures

#### 11.1.1.6.1 Screening Model Selection

The screening methodology to be used is selected in coordination with the appropriate federal, state, or local agencies. Technical considerations (based on the level of refinement required) that should be made include the appropriate averaging periods for acceptable ambient concentrations; source release characteristics (e.g., point, area, or line / volume sources; elevated or ground-level releases); the topography of the site and surrounding area; and the availability of appropriate meteorological data. As discussed earlier, the averaging period determines the selection of a short- or long-term screening model. Source release charateristics influence the selection process by defining the need for either simplistic models (e.g., one source or source type) or more sophisticated models (e.g., multiple source types and release characteristics). Topography and receptor locations influence the selection process by defining the need for models capable of representing airborne pollutant transport over flat, rolling, or complex terrain. Screening models approved by the U.S. EPA are provided in the *User's Network for Applied Modeling of Air Pollution (UNAMAP),* Version 6 (U.S. EPA, 1986). U.S. EPA provides guidelines for screening model selection and application (U.S. EPA, 1977, 1981b, and 1986). The project meteorologist and air quality analyst should be familiar with this guidance and with the available screening models before coordinating with the appropriate regulatory agencies.

#### 11.1.1.6.2 Meteorological Data Selection

Screening model analyses are generally made before site-specific meteorological data are available. This process requires the selection of a meteorological database that will provide a conservation assessment of the air quality impact at the hazardous waste site and surrounding area. The selection of meteorological data for use in screening assessments depends on the level of refinement of the modeling methodology and the representativeness of the available data. These input data vary from selected "worst case" meteorological scenarios to a source of data, such as the National Weather Service (NWS) whose routine observations are archived by the National Climatic Data Center (NCDC) in Asheville, North Carolina. Data from the Federal Aviation Administration (FAA) and military stations (U.S. EPA, 1981c, p. 5) or from universities, industry, pollution control agencies, and consultants (U.S. EPA, 1980, p. 31) may be used if these data are equivalent in accuracy and detail to the NWS data. The project meteorologist and air quality analyst must determine the representativeness of any offsite data and the validity of their use, along with the screening model, in providing a conservative assessment. The representativeness depends on the proximity of the station to the area under consideration, the complexity of the terrain, and the exposure of the meteorological monitoring equipment at the station. This selection process is also made in consultation with the appropriate regulatory agencies. Model selection governs the specific meteorological data that are required as input. For short-term analysis, screening models employ a "worst case" meteorological scenario. This scenario may consist either of a specific worst-case meteorological condition or a comprehensive set of meteorological conditions that, when evaluated, will determine the worst-cast meteorology.

Long-term models require that hourly meteorological data be summarized over longer periods of time (e.g., months, seasons, years). Hourly wind speed, wind direction, and atmospheric stability are reformatted into a stability array (STAR). If determined to be representative, STAR data sets compiled by the NCDC for NWS stations throughout the United States (U.S. NCDC, 1983) could be used. Otherwise, the assumptions described for long-term screening in U.S. EPA, 1977, should be used. The average temperature and the average morning and afternoon mixing heights are required inputs of the long-term models. Mixing height data have been summarized on seasonal and annual bases by Holzworth, 1972, for 62 NWS stations in the United States. The NCDC can also compile daily morning and afternoon mixing-height data for NWS stations that routinely make balloon-borne measurements of meteorological conditions in the upper air (above ground). Since the spatial coverage of NWS stations making these measurements is not dense, the project meteorologist and air quality analyst must carefully select the most representative source of the data to be used.

#### 11.1.1.7 Source Term Development

Another concern in modeling releases from a hazardous waste site is the determination of the source configuration (e.g., release type) and source term (i.e., emission rates). Source term determination can be complex for many types of sites such as surface impoundments, landfills, and land treatment facilities. The source term can be determined with a specifically designed onsite monitoring program, which is receptor modeling based on near-site monitoring or on air emission modeling. Emission modeling guidance is summarized in U.S. EPA, 1981b, and in GCA Corporation, 1983. Appropriate, conservative assumptions for emission rates can be applied for screening model analyses. Determination of the source configuration should be accomplished in conjunction with the SM after careful consideration of all possible release scenarios.

#### 11.1.1.8 Region-Specific Variances

Besides the site-specific considerations to be made in selecting the appropriate screening model and meteorological input data, no region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 11.1.2 Meteorological Parameters for Refined Modeling Analyses

#### 11.1.2.1 Scope and Purpose

Refined modeling analysis uses site-representative hourly meteorological data. When such data are unavailable, onsite meteorological monitoring may be necessary. This subsection provides generic guidance for the site-specific measurement of meteorological parameters that may be required to make detailed short-term and long-term assessments of exposure to hazardous air pollutants through the use of refined models for estimating dispersion of gases and particulates. The need for refined model analyses will generally be identified as a result of the preliminary screening model analyses discussed in Subsection

11.1.1. The procedures indicated here are applicable for use for field work at hazardous waste sites. This subsection briefly discusses model selection with more specific guidance cited by reference. Specific models are not recommended since selection of an appropriate model depends on project- and site-specific considerations. Meteorological parameters that can be readily obtained from other data sources are identified. The references listed in Subsection 11.1.2.8 provide more detailed discussions of field measurement procedures.

### 11.1.2.2 Definitions

Definitions of key terms as they apply to this procedure are provided below. Subsection 11.1.1.2 contains additional definitions of terms used in Subsection 11.1.2.

**Atmospheric Diffusion**
The process by which minute particles of a substance that is suspended in the atmosphere are distributed throughout an increasing volume of air. This process, then, reduces the concentration of the substance since the amount of the substance relative to the amount of air is decreased. Atmospheric diffusion is controlled in the atmosphere by wind speed and atmospheric turbulence.

**Atmospheric Dispersion**
As used in the context of this procedure, atmospheric dispersion combines the effects of atmospheric transport and diffusion on a substance.

**Atmospheric Stability**
Terms that describe the ability of the atmosphere to diffuse (see "atmospheric diffusion") a substance. An unstable, turbulent atmosphere provides for more diffusion than a stable atmosphere. For use in dispersion modeling and impact assessment, stability is represented by Pasquill-Gifford stability Classes A (unstable) through F (stable).

**Atmospheric Transport**
The process by which a substance is carried through the atmosphere.

**Mixing Height**
The height above the surface through which relatively vigorous vertical mixing occurs.

**Refined Model**
An analytical technique that provides a detailed treatment of physical and chemical atmospheric processes and requires detailed and precise input data. The estimates are more accurate than those obtained from conservative screening techniques.

**Sigma Theta**
Terms that describe the measure of variability of the wind direction. Sigma theta is used as an indicator of the diffusion capacity of the atmosphere and can be used to classify atmospheric stability.

### 11.1.2.3 Applicability

The purpose of conducting refined model analyses is to provide a more accurate and representative estimate of the impacts of a specific source (U.S. EPA, 1978, p. 17). These analyses are conducted when a potential for exceeding an acceptable ambient concentration of a hazardous air pollutant has been determined through screening model analyses (STAPPA/ALAPCO, 1984, p. 136).

As Subsection 11.1.1.3 indicates, acceptable concentrations of hazardous air pollutants (and standards based on these acceptable levels) are currently evolving. Refined model analyses may also be required in situations in which source and/or receptor characteristics are complicated (see Subsection 11.1.2.6.1). The meteorological input data requirements differ between models that produce short-term and long-term concentration estimates. These requirements are discussed in Subsection 11.1.2.6.2.

### 11.1.2.4 Responsibilities

**Project Meteorologist:** This person is responsible for the collection of site-specific meteorological data and/or selection of other representative meteorological parameters. Using input from project management, technical personnel, and appropriate regulatory agencies, the project meteorologist would design the measurement program; oversee the data collection, validation, and quality assurance procedures; and maintain records that document these activities.

**Project Meteorologist and Air Quality Analyst:** This person is responsible, through coordination with the appropriate regulatory agencies, for selecting appropriate refined model(s), performing model calculations, evaluating and reporting results, and maintaining records that document these activities.

**Site Manager:** The SM is responsible for the program design and coordination. The project engineer also interacts with the project meteorologist in modeling and monitoring applications including source term development.

**Field Maintenance Engineer:** This person is responsible for installing, calibrating, maintaining, and decommissioning the designed program, and for maintaining records that document these activities.

### 11.1.2.5 Records

Maintenance of records of the meteorological data collection program is required for validation purposes and future use in air quality modeling. These records include not only the data themselves (data can be recorded on an analog strip for future data reduction, digitally on hard copy such as a printer, or digitally on a magnetic tape) but also appropriate calibration and operational logs. These logs document activities performed on the instrumentation for future use in validation. Selection and determination of the representativeness of meteorological parameters, if applicable, should be documented, as well as the selection, application, and results of the refined model analyses.

Depending on the level of validation and quality assurance applied, additional records to be maintained could include system design drawings, data review logs, data correction logs, audit documents, instructions for data handling and use, and so forth. The level of detail in these records must support the quality assurance requirements of the program, which are to be established before collecting data.

### 11.1.2.6 Procedures

#### 11.1.2.6.1 Refined Model Selection

The refined dispersion model(s) to be used is selected in cooperation with the appropriate federal, state, and local regulatory agencies. The same technical considerations made during selection of an appropriate screening model apply in selection of refined models (see Subsection 11.1.1.6.1), although relatively more detailed input is often required because the refined models are more sophisticated.

The nature of atmospheric releases from hazardous waste sites dictates the need for a detailed evaluation of the appropriate model type and methodology to be applied. Depending on the source characteristics, the model may have to account for neutrally buoyant (i.e., approximately the same density as air), lighter-than-air, or heavier-than-air plumes; continuous or instantaneous (i.e., puff) releases; gases or particulates; a single or many individual point sources or area sources; and an urban or rural environment. Consideration of these source characteristics plus the required application (i.e., short- or long-term assessment) will influence model selection. In addition, it may be necessary to consider removal and transformation processes on the pollutant as it is transported downwind. Examples of these processes are gravitational settling, adsorption, and oxidation. Models with appropriate algorithms must be selected to account for these processes.

As with screening models, determination of the appropriate source term is an important factor in refined modeling and in the analysis of the results (see Subsection 11.1.1.7). Since refined modeling attempts to provide a more realistic and accurate assessment, source term and source characteristic assumptions should be representative of expected conditions.

A set of refined models is available through the U.S. EPA Exposure Evaluation Division, Office of Toxic Substances. The modeling system, known as Graphical Exposure Modeling System (GEMS), consists of a series of atmospheric models with various levels of refinement (GSC Corporation, 1984). These models can also be used for screening assessments. In addition to atmospheric models, GEMS includes models capable of assessing contaminant migration in surface water, ground water, and soils. Examples of EPA-approved atmospheric models available for use through GEMS include CDM, ISCST, and ISCLT. These computer codes can address short-term and/or long-term assessments with various source configurations. Some GEMS models also can account for removal and transformation mechanisms. Based on expected considerations at a hazardous waste site, the ISC computer code will probably be the most applicable model for many evaluations. The previously mentioned EPA-approved computer codes are also available through the UNAMAP on computer tape (U.S. EPA, 1986). UNAMAP also contains many other EPA-approved codes that may apply to some hazardous waste sites. All the UNAMAP models are also available through GEMS.

The GEMS atmospheric models do not account for all types of site-specific source and atmospheric dispersion considerations. The U.S. EPA is formulating guidance for the use of refined models with sources in complex terrain. Appropriate models may include accurate wind field analysis to account for terrain-induced variations in plume transport. In lieu of an adequate refined model that appropriately accounts for plume transport, complex terrain screening models (e.g., VALLEY) may need to be used and the results evaluated on a site-specific basis, considering model limitations as related to the intended application. Another consideration is models that can account for nonuniform or instantaneous releases. An example of a model that can address dispersion in complex terrain, as well as instantaneous releases, would be a plume element type such as a three-dimensional puff model. The ERT Model for Pipeline Ruptures (Hanna, 1982), the SPILLS Model (Fleisher, 1980), and the PFPL Model (Garrett and Murphy, 1981) are examples of plume element / puff models.

Another modeling concern for hazardous waste sites is the transport and diffusion of heavier-than-air gases. Various field measurement programs and analyses of the physical concepts of dense gas dispersion show that standard, Gaussian atmospheric diffusion models (e.g., the EPA-approved models) are inadequate until the plume has been diluted to where its density approximates that of the ambient air. This situation will occur at some distance from the source. The initial dispersion of dense gases is described by low, flat plumes that disperse in part because of their own density. Unless modified, Gaussian models cannot simulate this. Accordingly, if dense gas dispersion must be considered, especially close to the source, an appropriate model must be used. Discussions of dense gas dispersion modeling is provided in Britter and Griffiths (1982).

The project meteorologist and air quality analyst, when selecting the appropriate model for the application, must be familiar with any technical shortcomings of the models. For example, because of concerns over source size versus downwind distance and the applicability of modeling dispersion parameters at close-in distances, EPA-approved models do not calculate concentrations at distances less than 100 meters from the source. Some evaluations at hazardous waste sites may require assessments at these short distances from the source. These special situations may require site-specific analyses and should be discussed with the appropriate regulatory agency for guidance and approval on proposed methodologies.

### 11.1.2.6.2 Meteorological Data Collection

Site-specific meteorological data are preferred when conducting screening or refined model analyses (U.S. EPA, 1978, p. 31). An onsite monitoring program is necessary when there is a lack of representative meteorological data. Collection of meteorological data in the field requires the design of a system that provides the necessary model input information and that takes into account the logistics of siting and operation. Some data are best collected from visual observations or other representative sources (e.g., NWS stations) rather than from erected, in situ towers. In practice, acquiring all of the meteorological inputs to the model(s) will often require a combination of all of these collection techniques.

Model selection governs the specific meteorological data that are required as inputs. Appropriate input parameters and averaging times for screening models producing short-term and long-term concentration estimates are described in Subsection 11.1.1.6.2. The averaging time for meteorological data measured onsite should be consistent with the project requirements. For meteorological parameters, a consecutive period of at least 15 minutes can generally be used to represent the 1-hour period (U.S. NRC, 1980, p. 11). These hourly parameters are input directly to the refined models.

The duration of the monitoring program depends on the application of the measurements. If the project requirements are to assess potential impacts during periods of site activity, then the meteorological data measured during these periods is directly applicable to modeling analyses. However, if the project requirements are to assess short-term and long-term impacts not specific to any period (which is the scope of Subsection 11.1), then the monitoring program should be of a duration that will include meteorological characteristics representative of conditions that would produce maximum impacts. In practice, it may be feasible to conduct the monitoring program only for less than a year. The EPA has prepared guidance on using data periods of less than 1 year (U.S. EPA, 1980, pp. 9, 39). However, it should be noted that this guidance was developed primarily in relation to the evaluation of "criteria" pollutants. Therefore, in applying this guidance to evaluations of noncriteria hazardous air pollutants, the project meteorologist and air quality analyst must establish the monitoring program requirements in cooperation with the appropriate regulatory agencies.

For data to be collected in the field, a system should be chosen for the required application. The monitoring system should be designed so that the measurements represent the conditions that determine atmospheric dispersion in the area of interest. Since the atmospheric conditions can vary dramatically with the physical characteristics of the surrounding area, the system (equipment and location) should be designed based on specific site characteristics and program objectives.

Discussions concerning the collection of various meteorological parameters are presented below. More specific guidance on siting, equipment specifications and accuracies, and applications has been prepared by the U.S. EPA (U.S. EPA, 1983; U.S. EPA, 1984), the U.S. Nuclear Regulatory Commission (U.S. NRC, 1980), and its successor, the U.S. Department of Energy (1984). In all cases, specifications and accuracies should be based on requirements determined according to the appropriate regulatory agencies.

The following discussions concern measurements to support atmospheric dispersion modeling using most regulatory agency-approved methodology and models for licensing and permitting activities. Some of the more refined models may require input data for meteorological parameters not discussed here. For special cases, the references provided in this compendium or by the appropriate regulatory agency should be consulted for the accepted measurement techniques.

### Horizontal Wind Speed

**Description:** Horizontal wind speed sensors (anemometers) are available in a number of different designs. The most common types are the rotational cup and the propellor anemometers. The cup sensors are generally more accurate. The design of the anemometer cups dictates the durability, sensitivity, accuracy, and response of the instrument. Three conical cups usually provide the best performance. Propellor anemometers (similar to windmills in design) revolve about a pivoted shaft that is oriented by a vane into the direction from which the wind is blowing. The number of blades normally varies from three to six. For most atmospheric dispersion studies, anemometers should have a starting threshold of 0.5 meters per second (m/sec) or less and a system (i.e., sensor through readout device) accuracy of ±0.2 m/sec.

**Applicability:** Measurement of horizontal wind speed is an important factor for determining the dispersive capability of the atmosphere. The speed of the wind provides an indication of the transport (e.g., travel speed) and diffusion of a pollutant and is a direct input to air quality models. Wind speed is an important parameter in plume rise and is used as a factor in determining an atmospheric stability class for some stability classification schemes.

### Horizontal Wind Direction

**Description:** Most sensors for measuring horizontal wind direction consist of a vane rotating on a fulcrum. The shapes and designs of the vane surface vary but are generally rectangular or curved. The vanes are designed to orient into the direction from which the wind is blowing. For atmospheric dispersion studies, wind vanes should have a starting threshold of less than or equal to 0.5 m/sec and a system accuracy of ±5 degrees.

**Applicability:** Horizontal wind direction is directly used as an indicator of pollutant transport and is used as a direct input to air quality models.

It is also preferred that the meteorological system be designed to calculate directly and to give the standard deviation of the horizontal wind direction fluctuations (sigma theta). Sigma theta provides an indicator of the atmospheric stability by measuring horizontal turbulence. Some atmospheric diffusion models use sigma theta as a direct input in determining horizontal plume dimensions. Care should be exercised with this method to ensure that the data are representative. It may be desirable, for example, to install the meteorological tower at a complex-terrain site to ensure that the sigma theta data reflect the surface inhomogeneity.

### Vertical Wind Speed and Direction

**Description:** Vertical wind speed and direction can be measured with a vertical propellor anemometer, a UVW anemometer, or a bivane. The vertical propellor anemometer has a propellor-type sensor mounted on a fixed vertical shaft. Since the propellor can reverse its direction, the sensor can indicate whether wind flows are directed upward or downward. A UV anemometer has three fixed propellors. Two, located 90 degrees apart, measure the horizontal wind vector (both magnitude and direction). The third, like the vertical propellor anemometer, is located on a vertical shaft at right angles to the first two. This anemometer will then measure the total (i.e., U, V, and W components) wind vector. The UVW anemometer, when coupled with an onsite microprocessor to reduce the data, can provide real-time displays of wind speed, azimuth (horizontal wind components), and elevation (vertical wind component). The bivane consists of a vane with two flat plates perpendicular to each other, counterbalanced and mounted on a gimbal that allows the vane to rotate horizontally and vertically. Unlike the UVW anemometer, it does not provide the wind speed (and hence all three wind vector components) unless mounted with a propellor anemometer in place on the counter weight. It does provide both the azimuth and elevation components of the wind direction.

Vertical wind measurement systems should have a starting threshold of less than 0.25 m/sec and an accuracy of ±0.2 m/sec for wind speed and ±5 degrees for wind direction. Because of the sensitivity of these types of instruments, long-term use in the field or use in harsh environments may necessitate special maintenance activities. Individual manufacturers should be consulted about each application.

**Applicability:** The measurement of vertical wind components may be required as input to certain refined atmospheric dispersion models. Some refined models may use atmospheric turbulence data directly to define vertical and horizontal plume spread instead of indirectly from stability class. These models use the standard deviation of horizontal and vertical wind direction fluctuations—sigma theta and sigma phi, respectively. Some models also use both sigma theta and sigma phi measurements classified into atmospheric stability class. Vertical wind speeds can be used for plume downwash considerations (e.g., onsite hazardous waste incineration). The reader should refer to the subsection on atmospheric stability for further discussion.

### Ambient Temperature

**Description:** The two most commonly used temperature measurement devices for air quality studies are the resistance temperature detectors (RTDs) and thermistors. Thermistors are electronic semiconductors that are made from certain metallic oxides. The resistance of the thermistor varies inversely with its absolute temperature so the electrical output through the sensor can provide an indication of the ambient temperature. The RTD is used in a similar manner. These RTD sensors are made of different pure metals such as silver, copper, nickel, or platinum. Normally, platinum provides the best material. The RTD operates on the principle that the electrical resistance of a pure metal increases with temperature.

Care must be taken to avoid solar radiation error in temperature measurements. This error can be avoided by using naturally or mechanically aspirated radiation shields. The radiation shields should face downward when mounted on a tower. Temperature system accuracies should be approximately ±0.5°C.

**Applicability:** The measurement of ambient temperature can be used to determine relative humidity when used with the dew point temperature or to determine source terms for air releases of chemicals when used in the calculation of vaporization or volatization rates. In addition, surface temperature is used to calculate mixing height. Temperature is also put in air quality models to determine plume rise for buoyant (lighter-than-air) atmospheric releases. Variation of ambient temperature helps characterize local meteorological conditions.

### Cloud Cover

**Description:** Cloud cover is best determined from data collected at a representative NWS station as there are trained observers available to provide this information. If representative NWS cloud cover data are not available, then the total amount of cloudiness above the apparent horizon should be estimated as a fraction (in tenths) by a visual observation (Turner, 1964).

**Applicability:** Instead of other data, cloud cover is used as one of the indicators of atmospheric stability in the Pasquill-Turner stability classification scheme. In this scheme, cloud cover, ceiling height, wind speed, and solar radiation are used to determine an atmospheric stability class (Turner, 1964).

### Ceiling Height

**Description:** A ceiling is defined as a layer of clouds that covers more than one-half of the sky. The height of a ceiling is best determined by experienced observers at NWS stations. It can be estimated visually at the waste site by determining the height of the lowest layer of clouds that cover more than 50 percent of the sky. It is necessary for the onsite observer to estimate only whether the ceiling is less than 7,000 feet, between 7,000 and 16,000 feet, or more than 16,000 feet, based on the application of this parameter (Turner, 1964). Rough estimates of altitude can be made by noting the types of clouds when the ceiling height observation is made. Cloud forms with bases of less than 7,000 feet generally include fair-weather cumulus, stratus and stratocumulus, and towering cumulus. Cloud forms with bases between 7,000 and 16,000 feet generally include altostratus, altocumulus, towering cumulus, and cumulonimbus. Cloud forms with bases higher than 16,000 feet are usually of the cirrus type. A pocket-sized cloud atlas may be a useful tool for the field observer.

**Applicability:** Ceiling height is used in the Pasquill-Turner stability classification scheme to determine atmospheric stability class.

Mixing Height

**Description:** Mixing heights are best determined from representative NWS stations that record upper air (i.e., above the surface) data. Instrumentation packages called radiosondes are carried aloft twice daily (7:00 a.m. and 7:00 p.m., EST) throughout the United States by nontethered balloons. These packages measure wind speed and direction, temperature, and humidity as they ascend. Algorithms exist to compute mixing heights from the data collected by the radiosonde. Care should be taken to select data from a representative station and for the appropriate time, as applicable. Subsection 11.1.1.6.2 discusses the sources of this parameter. Estimates of the mixing height can also be made at the site through the use of balloonsondes (tethered and nontethered balloons) and with remote sensors such as acoustic sounders. This equipment requires special expertise to use, to evaluate, and to apply the collected data.

**Applicability:** The mixing height is the level of the atmosphere below which pollutants could be mixed. Mixing height indicates the vertical limit of pollutant dispersion. It is also an important consideration in air quality model in for nonground-level releases, including ground-level sources with high effective-release heights (e.g., a large plume rise because of a fire).

Atmospheric Stability

Atmospheric stability can be determined in the field for air quality modeling applications by using a number of alternative methods. These methods use the applicable meteorological parameters discussed in previous subsections.

The Pasquill-Turner method of classifying atmospheric stability uses the combination of wind speed, incoming solar radiation, cloud cover, and time of day. This scheme is indicated in Exhibit 11-1.

The neutral Class D is assumed for overcast conditions during day or night.

The incoming solar radiation intensities are determined from the solar altitude (a function of time of day and day of the year) and modified for existing cloud cover and cloud ceiling height (Turner, 1964).

The EPA provides further guidance for adjusting sigma phi to account for increased surface roughness, and for adjusting the stability category to account for wind speed restrictions on the occurrence of unstable and stable conditions (U.S. EPA, 1981c). If measurements of sigma phi are not available, sigma phi may be determined using the transform:

## Exhibit 11-1
## CLASSIFICATION OF ATMOSPHERIC STABILITY BY THE PASQUILL-TURNER METHOD

| Surface Wind Speed (at 10m) m/sec | Day<br>Incoming Solar Radiation | | | Night | |
|---|---|---|---|---|---|
| | Strong | Moderate | Slight | Thinly Overcast or ≥4/8 Low Cloud | ≤3/8 Cloud |
| <2 | A | A-B | B | | |
| 2-3 | A-B | B | C | E | F |
| 3-5 | B | B-C | C | D | E |
| 5-6 | C | C-D | D | D | D |
| >6 | C | D | D | D | D |

If vertical wind direction fluctuations (sigma phi) or vertical wind speed fluctuations are collected, atmospheric stability may be classified as follows in Exhibit 11-2 (from U.S. EPA, 1966):

## Exhibit 11-2
## CLASSIFICATION OF ATMOSPHERIC STABILITY BY SIGMA PHI

| Stability Classification | Stability Categories | Sigma Phi Categories | | |
|---|---|---|---|---|
| Extremely unstable | A | | Sigma phi | 11.5 |
| Moderately unstable | B | 11.5 | Sigma phi | 10 |
| Slightly unstable | C | 10 | Sigma phi | 7.8 |
| Neutral | D | 7.8 | Sigma phi | 5 |
| Slightly stable | E | 5 | Sigma phi | 2.4 |
| Moderately stable | F | 2.4 | Sigma phi | |

$$_{ns}\text{ (Radians)} \quad = \quad _{nw}/^{c}$$

Where $_{ns}$ (Sigma phi) = The standard deviation fluctuations over a 1-hour period

$_{nw}$ = The standard deviation of the vertical wind speed fluctuations over a 1-hour averaging period

• = The average horizontal 10-m wind speed for a 1 hour averaging period (U.S. EPA, 1966)

Using the values of sigma theta computed from the meteorological system, atmospheric stability is classified as follows in Exhibit 11-3 (U.S. NRC, 1980):

**Exhibit 11-3**
**CLASSIFICATION OF ATMOSPHERIC STABILITY BY SIGMA THETA**

| Stability Classification | Stability Categories | Sigma Theta Categories | | |
|---|---|---|---|---|
| Extremely unstable | A | | Sigma theta | 22.5 |
| Moderately unstable | B | 22.5 | Sigma theta | 17.5 |
| Slightly unstable | C | 17.5 | Sigma theta | 12.5 |
| Neutral | D | 12.5 | Sigma theta | 7.5 |
| Slightly stable | E | 7.5 | Sigma theta | 3.8 |
| Moderately stable | F | 3.8 | Sigma theta | 2.1 |
| Extremely stable | G | 2.1 | Sigma theta | |

The U.S. EPA provides further guidance for adjusting sigma theta to account for increased surface roughness and for adjusting the stability category to account for low-level wind direction meander at night and wind speed restrictions on the occurrence of unstable and stable conditions (U.S. EPA, 1966).

Current EPA guidance (U.S. EPA, 1981c) recommends that when onsite meteorological data sets are being used, atmospheric stability categories should be determined from one of these schemes, which are listed in the order of preference:

- 1. Pasquill-Turner method using onsite data, which include cloud cover, ceiling height, and surface winds (approprimately 10-m height)
- 2. Sigma phi method
- 3. Sigma theta method
- 4. Pasquill-Turner method using onsite wind speed with cloud cover and ceiling height from a nearby NWS site

**Applicability:** The use of atmospheric stability is an important consideration in determining the atmospheric diffusion of a pollutant. Excellent diffusion conditions exist for the unstable categories, while poor diffusion occurs during stable conditions. Estimates of downwind pollutant concentrations are not possible unless atmospheric stability conditions are determined.

The EPA-preferred dispersion models used for short-term and long-term analyses are designed to recognize six stability classes, A through F. Stability classes determined by the Turner method and other associated meteorological data are directly applicable to these models. In the case of stability classes determined by the sigma theta method, Classes F and G and other associated meteorological data are combined into one class, which is designated F.

#### 11.1.2.7 Region-Specific Variances

Besides the site-specific considerations to be made in selecting the appropriate refined model and representative meteorological input data, there are no known region-specific variances for collecting meteorological data for use in refined modeling analyses. No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 11.1.3 Information Sources

The following references will be useful in providing additional, detailed information on meteorological monitoring.

Britter, R.E., and R.F. Griffiths. *Dense Gas Dispersion.* New York: Elsevier Scientific Publishing Company. 1982.

Fleisher, M.T. *Mitigation of Chemical Spills: An Evaporation / Air Dispension Model for Critical Spills on Land.* Houston, Texas: Shell Development Co. 1980.

Garrett, A.J., and C.E. Murphy, Jr. *A Puff-Plume Atmospheric Deposition Model for Use at SRP in Emergency Response Situations.* DP 1595. Aiken, South Carolina: Savannah River Laboratory. 1981.

GCA Corporation. *Evaluation and Selection of Models for Estimating Air Emissions from Hazardous Waste Treatment, Storage, and Disposal Facilities.* GCA-TR-82-83-G. May 1983.

GSC Corporation. *GEMS User's Guide.* June 1984.

Hanna, S.R. *Diffusion From Sour Gas Pipeline Ruptures.* Report PB-226. Concord, Massachusetts: Environmental Research and Technology, Inc. 1982.

Holzworth, G.C. *Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Through the Contiguous United States.* Office of Air Programs Publication Number AP-101. U.S. Environmental Protection Agency. January 1972.

National Climatic Data Center. *Star Tabulations, Master List.* Prepared by the National Climatic Data Center, National Environmental Satellite, Information, and Data Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. May 1983.

Randerson, D., ed. *Atmospheric Science and Power Production.* DOE/TIC-27601. U.S. Department of Energy. July 1984.

STAPPA/ALAPCO. *Toxic Air Pollutant: State and Local Regulatory Strategies.* A survey conducted by the State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officials, Washington, D.C. January 1984.

Turner, D.B. "A Diffusion Model for an Urban Area", Journal of Applied Meteorology. February 1964. Pp. 83-91.

United States Code Annotated. *Title 42--The Public Health and Welfare, Section 9604.* As amended and enacted through May 15, 1983. Washington, D.C. 1983.

U.S. Congress. *The Hazardous and Solid Waste Amendments of 1984, Section 3019.* Washington, D.C. 1984.

U.S. Environmental Protection Agency, 1977. *Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10 (Revised): Procedures for Evaluating Air Quality Impact of New Stationary Sources.* Research Triangle Park, North Carolina: Office of Air Quality Planning and Standards. October 1977.

U.S. Environmental Protection Agency, 1978. *Guideline on Air Quality Models.* DAQ PS No. 1.2-080. Research Triangle Park, North Carolina: Office of Air Quality Planning and Standards. April 1978.

U.S. Environmental Protection Agency, 1980a. *OAQPS Guideline Series, Guideline on Air Quality Models.* Proposed Revisions. Research Triangle Park, North Carolina: Office of Air Quality Planning and Standards. October. 1980.

U.S. Environmental Protection Agency, 1980b. *Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD).* EPA 450/4 80-012. Research Triangle Park, North Carolina: Office of Air Quality Planning and Standards. November 1980.

U.S. Environmental Protection Agency, 1981a. "National Primary and Secondary Ambient Air Quality Standards." *Code of Federal Regulations* (40 CFR 81.344, amended through October 22, 1981).

U.S. Environmental Protection Agency, 198lb. *Evaluation Guidelines for Toxic Air Emissions from Land Disposal Facilities.* Washington, D.C.: Office of Solid Waste. August 1981.

U.S. Environmental Protection Agency, 1983. *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV Meteorological Measurements* EPA-600/4-82-060. Research Triangle Park, North Carolina: Environmental Montoring Systems Laboratory. February 1983.

U.S. Environmental Protection Agency, 1984a. "Proposed Guidelines for Carcinogen Risk Assessment; Request for Comments (Part VII)." *Federal Register (49 FR 46294-46301)*, Number 227. Washington, D.C. 23 November 1984.

U.S. Environmental Protection Agency, 1984b. "Proposed Guidelines for Exposure Assessment; Request for Comments (Part VIII)." *Federal Register (49 FR 46304-46312)*, Number 227. Washington, D.C. 23 November 1984.

U.S. Environmental Protection Agency, 1984c. "Proposed Guidelines for Mutagenicity Risk Assessment; Request for Comments (Part IX)." *Federal Register (49 FR 46314-46321)*, Number 227. Washington, D.C. 23 November 1984.

U.S. Environmental Protection Agency, 1984d. "Proposed Guidelines for the Health Assessment of Suspect Develop mental Toxicants and Requests for Comments (Part X)." *Federal Register (49 FR 46324 46331)*. Number 227. Washington, D.C. 23 November 1984.

U.S. Environmental Protection Agency, 1986. *User's Network for Applied Modeling of Air Pollution (UNAMAP)*, Version 6 (Computer Programs on Magnetic Tape). NTIS No. PB 86-22361. Springfield, Virginia: National Technical Information Service. 1983.

U.S. Nuclear Regulatory Commission. *Proposed Revision 1 to Regulatory Guide 1.23, Meteorological Programs in Support of Nuclear Power Plants*. September 1980.

Weinberg, D.B., G.S. Goldman, and S.M. Briggum, 1983. *Hazardous Waste Regulation Handbook, A Practical Guide to RCRA and Superfund.* New York, New York: Executive Enterprises. 1983. (Authors are members of the law firm of Wald, Harkrader, and Ross, Washington, D.C.)

## 11.2 OTHER METEOROLOGICAL PARAMETERS

### 11.2.1 Scope and Purpose

This subsection provides guidance for the site-specific measurement of certain meteorological parameters used in evaluating air releases from a hazardous waste site and in determining the operation of various air sampling instrumentation. These parameters include precipitation, relative humidity / dew point, atmospheric pressure, incoming solar radiation, soil temperature, evaporation, and visibility. The procedures indicated in this subsection are applicable for use during fieldwork at these sites. More detailed discussions are provided in the references listed in Subsection 11.2.8.

### 11.2.2 Definitions

Definitions of key terms as they apply to this procedure are provided below. Subsection 11.1.1.2 gives generic definitions for this section.

**Dew Point Temperature**
The temperature to which a given parcel of air must be cooled at constant pressure and constant water vapor content for water saturation to occur.

**Incoming Solar Radiation**
Also referred to as "insolation," the total electromagnetic radiation emitted by the sun and falling on the earth.

**Relative Humidity**
The ratio (normally expressed in a percentage) of the actual water vapor content of the atmosphere to the amount of water vapor when the atmosphere is saturated.

### 11.2.3 Applicability

The collection of site-specific meteorological data, other than those parameters required for dispersion model analyses, may be necessary for evaluating air releases from hazardous waste sites and for determining the operation of various air sampling instrumentation. The level of sophistication in the design of the meteorological monitoring program depends on how the particular data are applied. These data primarily support other activities associated with a hazardous waste site investigation (e.g., operating air sampling instruments, interpreting air sampling results, determining volatilization and vaporization rates of hazardous substances into the air). The applicability of each parameter to other activities is discussed in Subsection 11.2.6.1.

## 11.2.4 Responsibilities

**Project Meteorologist:** This person is responsible for the collection of site-specific meteorological data and/or selection of representative meteorological parameters from other data sources. The project meteorologist, using input from project management, technical personnel, and appropriate regulatory agencies, will design the measurement program; oversee data collection, validation, and quality assurance procedures; and maintain records that document these activities. In addition, the project meteorologist will provide any meteorological data required by other program personnel involved in the air sampling program or in the analysis of those results.

**Field Engineer:** This person is responsible for installation, calibration, maintenance, and decommissioning of the designed program, and for maintaining records that document these activities.

## 11.2.5 Records

Maintenance of records of the meteorological data collection program is required for validation purposes and future use in air quality assessments. These records include not only the data themselves (data can be recorded on an analog strip for future data reduction, digitally on hard copy such as a printer, or digitally on a magnetic tape) but also appropriate calibration and operational logs. These logs document activities that are performed on the instrumentation for future use in validation. Selection and determination of the representativeness of meteorological parameters, if applicable, should be documented.

Depending on the level of validation and quality assurance applied, additional records to be maintained could include system design drawings, data review logs, data correction logs, audit documents, instructions for data handling and use, and so forth. The level of detail in these records must support the quality assurance requirements, which are to be established before making refined model analyses or conducting air sampling programs.

## 11.2.6 Procedures

### 11.2.6.1 Meteorological Data Collection

Collecting meteorological data in the field requires the design of a system that addresses the project requirements as well as the logistics regarding siting and operation. Some required data are best collected from visual observations or other representative sources (e.g., NWS stations) rather than from in situ sensors. In practice, acquiring all of the meteorological data to meet program requirements will often require some combination of all of these collection techniques.

For parameters that are to be collected in the field, monitor placement or siting is important. Monitor placement is intended to site the sensors so that the measurements made are representative of the conditions in the area of interest. Depending on the complexity of the terrain in the area of interest and the parameters being measured, more than one measurement location may be required.

Discussions concerning the collection of various meteorological parameters are presented below. Subsection 11.2.8 contains more specific guidance on siting, equipment specifications and accuracies, and applications of the parameters discussed below.

### Precipitation

**Description:** The recording gauge is the primary precipitation monitor for use in air quality assessments. Recording gauges not only provide the total precipitation but measure the time of the beginning and ending of the precipitation and the rate of fall. There are two basic types of recording gauges—the weighing gauge and the tipping bucket gauge. Both can record liquid or frozen precipitation. Frozen precipitation is usually melted by some type of heating device incorporated into the gauge design. The weighing gauge, which is less precise than the tipping bucket type, normally incorporates a collector bucket and a drum-type recorder. As precipitation fills the bucket, the increasing weight moves a pen across the recorder, indicating the total amount. The tipping bucket-type directs the falling precipitation into buckets that tilt with each 0.01 inches of precipitation. The motion of the buckets causes a mercury switch closure. Each closure is indicated on a counter or recorder. The selected gauge should record precipitation totals with a resolution of 0.01 inches and an accuracy of ±10 percent. Measurements should be made near ground level and away from obstacles that could cause a nonrepresentative value.

**Applicability:** Precipitation measurements can be used as input to complex air quality dispersion models that can account for pollutant plume depletion by precipitation scavenging (i.e., pollutant washout). Care must be taken in applying precipitation data in this manner to assure that the measurements are representative of the area of interest. This care is necessary because precipitation, especially over short periods of time (e.g., 1 hour to 24 hours), tends to be variable over relatively short distances. If such an application is required, the project meteorologist needs to evaluate other available data sources or to expand the monitoring program by establishing a precipitation monitoring network that will satisfy the model input requirements.

Precipitation measurements can also be used as a basis for examining groundwater and surface water migration of pollutants by leaching through soil and runoff.

### Relative Humidity / Dew Point

A wide range of sensors is available to monitor relative humidity or dew point. Instrument types vary from handheld sling psychrometers to sensitive electronic units that use an optical chilled-mirror technique. Some of these monitors provide relative humidity directly, and others provide dew point directly. For recording systems in the field, relative humidity sensors that incorporate a capacitor (the electrical characteristics of which vary with humidity or hygroscopic materials that undergo dimensional changes from absorption of moisture) have been used. Dew point sensors using the chilled-mirror technique, or sensors that undergo chemical changes because absorption or adsorption of moisture, are commonly used. The dew point sensors are generally more reliable and accurate. Dew point or relative humidity monitoring equipment should be installed with the same considerations given to temperature measurements (see Subsection 11.1.2.6.2). The height of the measurement should be based on the program requirements, but care should be taken to avoid any nonrepresentative near-ground effects. The accuracy of the selected system should be contingent on the project requirements and applications. The reader should refer to the manufacturer's literature to determine appropriate accuracies and measurement limitations.

**Applicability:** Values of atmospheric humidity (relative humidity can be calculated from the dew point temperature and ambient dry bulb temperature) are used to determine vaporization or evaporation rates of volatile compounds. Relative humidity is also important in an air sampling program, because it can indicate the efficiency of certain filters in collecting various chemical compounds.

### Atmospheric Pressure

**Description:** Atmospheric pressure is measured with barometers that operate with different types of sensors. Analog signal-output barometers that are used in the field sense variations in pressure primarily with aneroid (or bellows) cells that flex as the pressure changes. Other types of barometers use techniques such as capacitors, which change in electrical characteristics as the pressure changes. Most of these barometers can attain a ±0.5 millibar accuracy or better, which is adequate for hazardous waste site applications.

Atmospheric pressure can also be obtained using handheld aneroid barometers, which use a dial readout or a microbarograph that uses a direct mechanical readout on a chart. Both of these barometers provide sufficient resolution (1.0 millibar graduations or better). Atmospheric pressures for different averaging times are not easily provided with the handheld barometer since these barometers would provide only "instantaneous" values. Since barometric pressure is a conservative parameter (i.e., variations with time are normally small), this pressure may not be a major consideration. Pressure measurements should be made near ground level and should reflect the outside pressure at the measurement location. Another source of atmospheric pressure is from a representative NWS station. The NWS can provide actual station pressure or pressure corrected to sea level for station elevation.

**Applicability:** Atmospheric pressure is used to calculate vaporization or evaporation rates of chemical compounds. Pressure is also used in an air sampling program to determine flowrates for sampling pumps (see Subsection 11.4.6). Both of these applications require the station pressure, not a value corrected for elevation.

### Incoming Solar Radiation

**Description:** Incoming solar radiation (insolation) is measured with instruments known as pyranometers. These instruments measure the solar radiation received from the hemispherical part of the atmosphere it sees. The pyranometer is mounted near ground level facing toward the sun's zenith. Care should be taken to avoid possible local interference from nearby obstructions that could block the incoming solar radiation (i.e., there should be no shadows). Logistics of the measurements dictate daily inspections and data validation. Accuracy requirements should be based on the final application of the data.

**Applicability:** Normally, solar radiation measurements are secondary to wind and temperature measurements in air quality evaluations. The solar radiation data can be directly related to atmospheric stability. Existing standard air quality models do not currently use measured solar radiation data. Models to compute rates of chemical volatilization or vaporization may use solar radiation data quantitatively.

### Soil Temperature

Soil temperatures can be measured with any of the temperature sensors discussed in Subsection 11.1.2.6. A representative surface temperature of the soil into which a contaminant has been deposited should be determined. The depth at which this measurement should be made varies with soil type. Typically, a measurement of 1 to 5 cm depth is used. Care must be exercised to not disturb the soil when making the measurement.

**Applicability:** Soil temperature measurements are used to determine vaporization rates of chemicals spilled on the ground surface.

Evaporation Data

The measurement of evaporation in the field is a difficult and imperfect procedure. Most measurements involve the same type of instrumentation used by the NWS, a Class A evaporation pan. This pan is mounted near the ground on supports, and measurements of water loss are made routinely. These pans must be carefully maintained and monitored. Instead of obtaining these data onsite, it would be preferable to obtain the information from a representative NWS station that makes these measurements or to calculate climatological average values with any of several equations available.

**Applicability:** These data can indicate evaporation from lagoons or ponds (and hence a source term) although the relationship between the evaporation rate of the liquid with the chemical makeup of the lagoon or pond compared to that of the pan must be considered. In addition, the relationship between the pan evaporation and evaporation over a larger water body must be considered. Long-term evaporation data, along with precipitation data from representative sources, can also indicate the potential for contaminants to leach to groundwater.

Visibility

**Description:** A wide variety of instrumentation is available to measure visibility in the field. Some of these instruments were developed for use in aviation while others were developed specifically for air pollution applications. Instruments such as nephelometers and transmissometers are simple to use in the field, but detailed calculations are required to convert their readings to meaningful values for visibility. Other instruments such as telephotometers are more difficult to use and, like nephelometers and transmissometers, require calculations for visibility determinations.

Studies have shown that the more subjective method of observing visibility with the human eye provides results comparable to the field instruments.

Use of the human eye to determine visibility is based on observing techniques of the NWS. In its simplest form, the technique for using the human eye is to select markers at various distances in the direction(s) of interest, determine the distance of these markers from the observation point, and then estimate visibility by noting which markers can be seen. The distance at which the markers are placed and the separation distance depend on the project requirements and the availability of objects that can serve as markers. Visibility markers should be at least 1/2 degree in angular size. (The object, when held at arm's length, will fill a 5/16-inch diameter hole.) Daytime markers should be dark, while nighttime markers should be unfocused lights of moderate intensity.

**Applicability:** Visibility measurements can indicate the relative impact on visual impairment of pollutant releases to the atmosphere.

### 11.2.7 Region-Specific Variances

No region-specific variances are known to exist for the measurement of the meteorological parameters discussed in this subsection; however, any future variances will be incorporated in subsequent revisions to this compendium. Because information on variances may become dated rapidly, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 11.2.8 Information Sources

More detailed information concerning measurements and applications of the meteorological parameters discussed in this subsection are listed below: Air Pollution Control Association. *Proceedings, View on Visibility—Regulatory and Scientific*. November 1979.

Bruce, J.P., and R.H. Clark. *Introduction to Hydrometeorology*. New York: Pergamon Press. 1969.

Fritschen, L.J., and L.W. Gay. *Environmental Instrumentation*. New York: Springer-Verlag. 1979.

Thibodeaux, L.J. *Chemodynamics, Environmental Movement of Chemicals in Air, Water, and Soil*. New York: John Wiley and Sons. 1979.

U.S. Environmental Protection Agency. *Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurements*. EPA-600/4-82-060. Research Triangle Park, North Carolina: Environmental Monitoring Systems Laboratory. February 1983.

## 11.3 AIR QUALITY

Air quality measurements employ a number of instruments and techniques. Section 15 of this compendium discusses a number of the more commonly used direct-reading field instruments. This subsection discusses the general air and gas sampling methods for determining air quality.

### 11.3.1 Scope and Purpose

This subsection applies to field air quality monitoring and air sampling activities related to site characterization activities. It describes the methods and equipment necessary for real-time air quality monitoring in the field, and for collecting air samples for laboratory analysis. With regard to site characterization activities, real-time monitoring will help in selection of sampling locations and screening of samples (e.g., screening of split-barrel samplers to select samples for laboratory analysis). Real-time monitoring is also used for health and safety purposes. Air samples collected for laboratory analysis can be used for characterizing the atmospheric transport of contaminants and for risk assessment.

### 11.3.2 Definitions

**Continuous Monitoring Instrument**

An instrument that gives quantified measurements of the concentration of usually only one specific pollutant (e.g., CO, $H_2S$, $SO_2$) on a real-time basis. A variety of instruments can be used for this purpose, including GC, UV, and IR devices.

**Detector Tubes**

Small glass tubes filled with solid adsorbents, such as silica gel, activated alumina, or inert granules, and impregnated with detecting chemicals through which air is aspirated at a controlled rate. The detector chemical undergoes a color change in the presence of the contaminant; the contaminant concentration is proportional to the intensity of color change, or the length of the stain. Detector tubes are also known variously as "colorimetric tubes" or "indicator tubes."

**Direct Reading Instruments (DRIs)**

Instrumentation operating on flame-ionization, photoionization, or infrared principles providing real-time readings of ambient contaminant, usually in parts per million in air.

**FID Meter**

A portable air monitoring instrument (e.g., OVA-128) that operates by flame-ionization detection (see Section 15).

**PID Meter**

A portable air monitoring instrument (e.g., HNU PI-101) that operates by photoionization detection (see Section 15).

**Representative Sampling**

Sampling over a fixed period of time, usually 8 to 24 hours, using a sorbent medium (for volatiles) or filter (for particulate material) to determine the representative concentration of a contaminant in the air volume sampled.

**Sorbent Sampling Medium**

A material that quantitatively adsorbs volatile or semi-volatile organic compounds from air passing through the medium. These compounds are desorbed in the laboratory (using solvents or thermally) and analyzed. Commonly used sorbent media include Tenax, XAD resins, and activated carbon.

## 11.3.3 Responsibilities

**Site Manager:** The SM is responsible for determining the need for, and scope of, an air monitoring and sampling program.

**Field Team Leader:** This person is responsible for implementing the air monitoring program as it is detailed in the work plan and Quality Assurance Project Plan (QAPjP) for the specific site. Air monitoring requirements may be included in both the work plan and the site-specific health and safety plan. In the case of air monitoring for health and safety requirements, the site safety officer has a lead role in evaluating the data and taking required action as detailed in the health and safety plan.

## 11.3.4 Procedures

### 11.3.4.1 Introduction

The purpose of air and gas sampling is to define the concentration of airborne contaminants in a discrete air mass. Because of the wide spectrum of measurement technology and expense of instrumentation, it is critical to clearly define the data quality objectives of the air sampling program. Key considerations are pollutant(s) of interest, turnaround time required for results, sampling frequency, degree of measurement accuracy required, and the level of quality assurance / quality control (QA/QC) documentation required for the intended use of the data.

An initial screening program should be included during site reconnaissance activities for sites that may have significant onsite levels and/or offsite transport of airborne contaminants. This screening will help to refine or redefine the air monitoring requirements for the remedial response activities. The screening would be accomplished using an FID (e.g., OVA), PID (e.g., HNU), and possibly air sampling pumps and/or detector tubes. The results of the screening will provide input to the site safety plan and help in selecting the proper site and the number of sampling locations.

Continuous air monitoring is performed by drawing air samples continuously from one or more fixed sampling points. The analyzing instrument may be located at or very near the point of air aspiration or may be several hundred feet from the sampling locations.

When long sampling lines are used, transport time to the analyzer must be taken into account when relating the contamination episodes near the sample point to the real-time analytical record reported at the analytical instrument. Similarly, it should be noted that if the analyzer draws samples successively from several sampling points, important contaminant-releasing events could be missed if sampling was not occurring from the nearest sampling point at the moment of release.

Analytical instrumentation for continuous monitoring may use fixed- or variable-wave-length UV, IR spectrographic, flame-ionization, or electrochemical detection principles. Fixed-site analytical devices for continuous sampling may require AC power, weatherproof housing, climate control, and various laboratory-grade compressed gases.

Fixed-site continuous monitoring is expensive and uses complex analytical equipment. Monitoring may be used to provide the detailed input necessary for atmospheric simulation modeling or may provide an early emergency warning and/or a legal record when extremely toxic contaminants or sensitive community relations are involved at the site.

Representative air sampling is subdivided into two general categories: gaseous and particulate. The two principal methods for gaseous sample collection are adsorption of the compounds of interest onto sorbent media (such as Tenax, activated carbon, or XAD resin) through which a metered volume of gas has been passed, or collection of a gas sample in a bag constructed of nonreactive material such as Mylar. In all cases using sorbent media, two tubes must be linked in series to evaluate breakthrough from the first tube in the series. Tables of breakthrough values for most common volatile organics are available from the sorbent suppliers; if the concentration in the first tube approaches a breakthrough value, the second tube should be analyzed. Alternately, a two-phase tube with tandem sorbent media may be used.

Use of sorbent media for air sampling is further described below. Particulate (aerosol) sampling is generally performed using a high-flow pump (about 2 liters per minute) to which a filter assembly is attached. Commonly, filters with 0.8 micron average pore size are used. Calibration and use of air sampling pumps are described in Subsection 11.3.4.3.

### 11.3.4.2 Air Monitoring

Air monitoring is used to help establish criteria for worker safety, to document potential exposures, to determine protective measures for the public, to evaluate the environmental impact of the site, and to determine mitigation activities. An effective air surveillance program, tailored to meet the conditions found at each work site, must be established to accomplish these tasks.

Air contaminant data, including any changes that occur, are needed during site operations. Surveillance for vapors, gases, and particulates is accomplished using DRIs and air sampling systems. DRIs can be used to detect many organics and a few inorganics and to provide approximate total concentrations. If specific organics (and inorganics) have been identified, then DRIs calibrated to those materials can be used for more accurate onsite assessment.

The most accurate method for evaluating any air contaminant is to collect samples and analyze them at a reliable laboratory. Although accurate, this method has two disadvantages: the cost and the time required to obtain results. Analyzing large numbers of samples in laboratories is very expensive, especially if results are wanted quickly. Onsite laboratories tend to reduce the turnaround time, but unless they can analyze other types of samples, they also are costly. In emergencies, time is often not available for laboratory analysis of samples either onsite or offsite.

To obtain air monitoring data rapidly at the site, site operations may include instruments using flame-ionization detectors (FIDs), photoionization detectors (PIDs), and other similar instruments. This equipment may be used as survey instruments (total concentration mode) or operated as gas chromatographs (gas chromatograph mode). As gas chromatographs, these instruments can provide real-time qualitative / quantitative data when calibrated with standards of known air contaminants. Combined with selective laboratory analysis of samples, they provide a tool for evaluating airborne organic hazards on a real-time basis, at a lower cost than analyzing all samples in a laboratory.

### 11.3.4.3 Air Sampling

For more complete information about air contaminants, measurements obtained with DRIs must be supplemented by collecting and analyzing air samples. To assess air contaminant more thoroughly, air sampling devices equipped with appropriate collection media are placed at various locations throughout the area. These samples provide air quality information for the period of time they operate; they can indicate contaminant types and concentrations over the entire period of site operations. As data are obtained (from the analysis of samples, DRIs, knowledge about materials involved, site operations, and potential for airborne toxic hazards), adjustments are made in the type of samples, number of samples collected, frequency of sampling, and analysis required. In addition to air samplers, area sampling stations may also include DRIs equipped with recorders and operated as continuous air monitors. Area sampling stations may be located in various places, as dictated by project and site needs:

- **Upwind:** Because many hazardous incidents occur near industries or highways that generate air pollutants, samples may be taken upwind of the site to establish background levels of air contaminants.

- **Support Zone:** Samples may be taken near the command post or other support facilities to ensure that they are in fact located in a clean area, and that the area remains clean throughout operations at the site.

- **Contamination Reduction Zone:** Air samples may be collected along the decontamination line to ensure that decontamination workers are properly protected and that onsite workers are not removing their respiratory protective gear in a contaminated area.

- **Exclusion Zone:** The exclusion zone represents the greatest risk of exposure to chemicals and requires the most air sampling. The location of sampling stations should be based upon hot-spots detected by DRIs, types of substances present, and potential for airborne contaminants. The data from these stations, in conjunction with intermittent walk-around surveys with DRIs, are used to verify the selection of proper levels of worker protection and exclusion zone boundaries, as well as to provide a continual record of air contaminants.

- **Downwind:** One or more sampling stations may be located downwind from the site to indicate if any air contaminants are leaving the site. If there are indications of airborne hazards in populated areas, additional samplers should be placed downwind.

### 11.3.4.4 Media for Collecting Air Samples

Remedial response activities concerning hazardous material, especially those activities conducted on abandoned waste sites, involve thousands of potentially dangerous substances—gases, vapors, and aerosols—that could become air borne. A variety of media—liquids and solids—are used to collect these substances. Sampling systems typically include a calibrated air sampling pump that draws air into selected collection media. Some of the most common types of samples and their collection media are described next.

**Organic Vapors:** Activated carbon is an excellent adsorbent for most organic vapors. However, other solid adsorbents (such as Tenax, silica gel, and Florisil) are routinely used to sample specific organic compounds or classes of compounds that do not adsorb or desorb well on activated carbon. To avoid stocking a large number of sorbents for all substances anticipated, a smaller number—chosen for collecting the widest range of materials or for substances known to be present—is generally used. The vapors are collected using an industrial hygiene personal sampling pump with either one sampling port or a manifold capable of simultaneously collecting samples on several sorbent tubes—for example, a manifold with four sorbent tubes (or individual pumps with varying flowrates). The tubes might contain the following:

- Activated carbon to collect vapors of materials with a boiling point above zero degrees Centigrade (0°C). These materials include most odorous organic substances (such as solvent vapors).
- A porous polymer (such as Tenax or Chromosorb) to collect substances (such as high-molecular-weight hydrocarbons, organophosphorous compounds, and vapors of certain pesticides) that adsorb poorly onto activated carbon. Some of these porous polymers also adsorb organic materials at low ambient temperatures more efficiently than carbon.
- A polar sorbent (such as silica gel) to collect organic vapors (such as aromatic amines) that exhibit a relatively high dipole moment.
- Another speciality adsorbent selected for the specific site. For example, a Florisil tube could be used if polychlorinated biphenyls are expected.

**Inorganic Gases:** The inorganic gases present at an incident would primarily be polar compounds such as the haloacid gases. These gases can be adsorbed onto silica gel tubes and analyzed by ion chromatography. Impingers filled with selected liquid reagents can also be used.

**Aerosols:** Aerosols (solid or liquid particulates) that may be encountered at an incident include contaminated and noncontaminated soil particles, heavy-metal particulates, pesticide dusts, and droplets of organic or inorganic liquids. An effective method for sampling these materials is to collect them on a particulate filter (such as a glass fiber or membrane-type filter). A backup impinger filled with a selected absorbing solution may also be necessary.

**Other Methods:** Colorimetric detector tubes can also be used with a sampling pump when monitoring for some specific compounds. Passive organic vapor monitors can be substituted for the active system described if passive monitors are available for the types of materials suspected to be present at a given site.

**Information Resource:** The National Institute for Occupational Safety and Health's (NIOSH) *Manual of Analytical Methods*, Volumes 1-7, contains acceptable methods for collecting and analyzing air samples for a variety of chemical substances. The reader should consult it for specific procedures.

### 11.3.4.5 Collection and Analysis

Samples are analyzed to determine the types and quantities of substances present. The following paragraphs provide additional guidance on sample collection and analysis.

**Aerosols:** Samples for aerosols should be taken at a relatively high flowrate (generally about 2 liters per minute) using a standard industrial hygiene pump and filter assembly. To collect particulates, a membrane filter having a 0.8 micrometer pore size is common. The sample can be weighed to determine total particulates, then analyzed destructively or nondestructively for metals. If the metals analysis is done nondestructively or if the filter is sectioned, additional analysis (for example, organics, inorganics, and optical particle sizing) can be performed.

**Sorbent Samples:** The sorbent material chosen, the amount used, and the sample volume will vary according to the types and concentrations of substances anticipated at a particular site. Polar sorbent material, such as silica gel, will collect polar substances that are not adsorbed well onto activated carbon and some of the porous polymers. The silica gel sample can be split and analyzed for the haloacid gases and aromatic amines.

Activated carbon and porous polymers will collect a wide range of compounds. Exhaustive analysis to identify and quantify all the collected species is prohibitively expensive at any laboratory and technically difficult for a field laboratory. Therefore, samples should be analyzed for principal hazardous constituents (PHCs). The selection of PHCs is based on the types of materials anticipated at a given site, on generator's records, and on information collected during the initial site survey. To aid in the selection of PHCs, a sample could be collected on activated carbon or porous polymer during the initial site survey and could be exhaustively analyzed offsite to identify the major peaks within selected categories. This one thorough analysis, along with what is already known about a particular site, could provide enough information to select PHCs. Standards of PHCs could then be prepared and used to calibrate instrument used for field analysis of samples. Subsequent routine offsite analysis could be limited to scanning only for PHCs, thereby saving both time and money. Special adsorbents and sampling conditions can be used for specific PHCs, if desired, while continued multimedia sampling will provide a base for analysis of additional PHCs that may be identified during the course of cleanup operations.

Other sample techniques involve the extraction or desorption of various solid sorbents. While many NIOSH analytical methods are available for a variety of individual compounds, the most useful methods in remedial response investigation involve some form of gas chromatography coupled with mass spectrophotometry identification (GC/MS).

The main advantage to GC/MS is the relatively high qualitative accuracy obtainable when looking for specific compounds. In addition, unexpected compounds can be identified by comparing sample mass chromatograms to the National Bureau of Standards' standard mass chromatograms. While this method is not infallible, it is very useful in identifying organic vapors at hazardous waste sites.

In addition, when using sorbent tubes, it is wise to check a certain number of traps to assure that they are not channeled or plugged, which would affect collection efficiency. This activity is accomplished by checking pressure drop across the trap.

**Passive Dosimeters:** A less traditional method of sampling is the use of passive dosimeters. The few dosimeters now available are only for gases and vapors. Passive dosimeters are used primarily to monitor personal exposure, but they can be used to monitor areas. Passive monitors are divided into two groups:

- **Diffusion Samplers:** Molecules move across a concentration gradient, usually achieved within a stagnant layer of air, between the contaminated atmosphere and the indicator material.

- **Permeation Devices:** These devices rely on the natural permeation of a contaminant through a membrane. A suitable membrane is selected that is easily permeated by the contaminant of interest and impermeable to all others. Permeation dosimeters are, therefore, useful in picking out a single contaminant from a mixture of possible interfering contaminants.

Some passive dosimeters may be read directly, as are DRIs and colorimetric length-of-stain tubes. Others require laboratory analysis similar to that for solid sorbents.

### 11.3.4.6 Personnel Monitoring

In addition to area atmosphere sampling, personnel monitoring, both active and passive, can be used to sample for air contaminants. Representative workers are equipped with personal samplers to indicate contaminants at specific locations or for specific work being done. Placed on workers, generally within 1 foot of the mouth and nose (breathing zone), the monitors indicate the potential for the worker to inhale the contaminant.

### 11.3.4.7 Calibration

As a rule, the total air sampling system should be calibrated, rather than the pump alone. Proper calibration is essential for correct operation and for accurate interpretation of resultant data. As a minimum, the system should be calibrated before and after use. The overall frequency of calibration will depend on the general handling and use of a given sampling system. Pump mechanisms should be recalibrated after repair, when newly purchased, and following suspected abuse.

### 11.3.4.8 Meteorological Considerations

Meteorological information is an integral part of an air surveillance program. Data concerning wind speed and direction, temperature, barometric pressure, and humidity, singularly or in combination, are needed for the following:

- Selecting air sampling locations
- Calculating air dispersion
- Calibrating instruments
- Determining population at risk or environmental exposure from airborne contaminants

Knowledge of wind speed and direction is necessary to effectively place air samplers. In source-oriented ambient air sampling, samplers need to be located at different distances downwind of the source and other samplers need to be placed to collect background samples. Shifts in wind direction must be known, and samplers must then be relocated or corrections must be made for the shifts. In addition, atmospheric simulation models for predicting contaminant dispersion and concentration need wind speed and direction as inputs for predictive calculations. Information may be needed concerning the frequency and intensity with which winds blow from certain directions (windrose data); consequently, the wind direction must be continually monitored when use of this type of data is contemplated.

Air sampling systems need to be calibrated before use, and corrections in the calibration curves should be made for temperature and pressure. After sampling, sampled air volumes are also corrected for temperature and pressure variations. This requires knowledge of air temperature and pressure.

Air sampling is sometimes designed to assess population exposure (and frequently potential worker exposure). Air samplers are generally located in population centers irrespective of wind direction. Even in these instances, however, meteorological data are needed for air dispersion modeling. Models are then used to predict or verify population oriented sampling results.

Proper data are collected by having meteorological stations onsite or by contacting one or more of several government or private organizations that routinely collect such data. The choice of an information gathering method depends on the availability of reliable data at the location desired, the resources needed to obtain meteorological equipment, the degree of accuracy of information needed, and the use of information.

### 11.3.5 Information Sources

U.S. Environmental Protection Agency. *Standard Operating Safety Guides.* November 1984.

National Institute for Occupational Safety and Health. *Manual of Analytical Methods.* Vols. 1-7. April 1977 through August 1981.

# SECTION 12

# BIOLOGY / ECOLOGY

## 12.1 SCOPE AND PURPOSE

Section 12 discusses the general types of field and laboratory activities that can be used to assess biological or ecological impacts resulting from remedial response activities at a hazardous waste site.

This section is divided into four basic components: (1) Introductory remarks about biological and ecological evaluations of hazardous waste sites (Subsections 12.1 through 12.6.2); (2) a summary of the methods and applications that have been used to date, and their limitations; (3) a list of references to lead a user to more details about methods (Subsection 12.8); and (4) Appendix 12A, which shows additional details on methods. The information sources subsection provides a partial list of methods sources that users should refer to if the site conditions or the questions being asked do not appear to be compatible with the methods described herein. The reader may also refer to "Standard Practice for Conducting Acute Toxicity Tests with Fishes, Macroinvertebrates, and Amphibians," *ASTM Designation E 729-80*, pages 285-309, by the American Society for Testing and Materials.

For purposes of this discussion, the greatest emphasis in Section 12 is placed on terrestrial habitats and the lowest emphasis is placed on marine habitats. Aquatic (freshwater) habitats are given intermediate emphasis because of the general pattern of hazardous waste site locations. To date, marine hazardous waste sites or sites associated with marine areas have been near the shore, generally in shallow water areas. Many of the study techniques described for aquatic (freshwater) studies will also work in marine areas.

In summary, this section is a compendium of past biological and limited ecological work that has been requested at hazardous waste sites. It includes other suggested methods that may work in some varying situations.

## 12.2 DEFINITIONS

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. This person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

All other terms in Section 12 are in common use. If a term is unfamiliar, the user should check the glossary.

## 12.3 APPLICABILITY

The information in this section is applicable to those hazardous waste sites in which the SM determines the need for such studies (see Subsection 12.4). Biological, especially ecological, investigations have not been a major requirement of remedial response activities in the past, however, requirements may change as more sophisticated evaluations of environmental impacts are required at selected sites.

Detailed biological or ecological studies are not always required. If other studies define the onsite and offsite contaminant migration patterns, this information may be adequate for the analysis and completion of remedial actions. However, the fact that some stated criterion (usually for single parameters) for a contaminant is or is not exceeded does not always result in an observable impact on biological systems. The biological impact projection process is made complex by contaminants that are often a mix of parameters, which may also vary in space and/or time. Single parameters may not exceed any known criterion; yet an impact may still be possible from such complex mixtures. Biological and ecological site investigations may be triggered in situations where questions exist about the presence or absence of measurable impacts both onsite and offsite.

Biomonitoring can be conducted to better determine whether the substances detected in soil, sediment, air, and water analyses are affecting or could affect natural systems either directly or through food chain accumulation and, if an impact is possible, what risk there might be to humans. There are two major types of biomonitoring: ecological surveys and individual assays. Ecological surveys involve comparing various ecological parameters, such as species diversity or abundance, in a reference or control site with the same parameters in an affected area. Individual assays include measuring tissue levels of contaminants in organisms collected on or near the site and from reference areas, as well as performing bioassays using site materials or leachates to test for toxicity and bioconcentration in various standard organisms. The determination of contaminant levels in the tissues of organisms that are consumed by humans can assist in human health risk assessment.

Control or reference areas are not necessarily considered to be free from any type of contamination, but rather these areas provide information on local background or ambient levels of contamination.

Because of project schedule and reference area constraints and because of the importance of immediate public health concerns, detailed ecological surveys have not often been conducted. Some limited ecological surveys, which focused on a segment of the community such as aquatic invertebrates, have been used to examine possible offsite contaminant migration. Biota tissue analysis and bioassays, both in situ and in the laboratory, have been the primary types of biological surveys conducted on hazardous waste sites.

## 12.4 RESPONSIBILITIES

The SM determines the need for biological and ecological surveys and tasks the necessary personnel to execute the study.

## 12.5 RECORDS

Field observations are kept in bound notebooks with numbered pages. Entries are initialed by the notetaker. Laboratory data are recorded on the appropriate forms and in logs. Photographs are recorded in the field notebook; the reader should see also Sections 6 and 17 of this compendium.

## 12.6 PROCEDURES

The following discussions describe the types of biological field sampling techniques and laboratory analyses that have been used or are being used in biological or ecological assessments of hazardous waste sites.

### 12.6.1 Presence of Toxic Substances

To determine site contaminants of concern, the project staff should review the results of soil, sediment, groundwater, and surface water testing and should list the priority pollutants present in these media. Then they should review data and make a final listing of onsite pollutants. The data should be compared to applicable or relevant and appropriate requirements, such as state and federal drinking water standards, and to ambient water quality criteria that have been established to protect either human health or aquatic systems. The methodology to use in this comparison is described in EPA's *Draft Superfund Public Health Evaluation Manual* (1985b), which focuses on human health protection. However, if the goal of the project is to protect aquatic ecosystems, emphasis should be placed on EPA's ambient water quality criteria as well.

Project personnel need to clearly define the overall objectives of the site sampling program, which includes physical parameter sampling, before designing the overall field sampling program. If a biological or ecological study is made at the site, an environmental scientist must become involved early in the determination of initial physical parameters for the field sampling program and for any subsequent sampling programs. Biological or ecological studies often cannot be redesigned around the physical parameter of sampling programs that are intended for other purposes.

Site Managers should note that an increase in parameter testing or a requirement for lower detection limits to allow comparison to water quality criteria can dramatically increase study costs. For example, aquatic life criteria for chromium are set separately for the two chromium species, chromium VI and chromium III (EPA, 1980a and 1985a). Data on total chromium are not adequate to determine whether criteria have been exceeded. The cost increases for additional analyses may have to fit into available budgets. In some cases, added costs for better biological and ecological assessments will be at the expense of other studies. Therefore, biological and ecological studies must be well thought out and must justify the added time and the costs required to complete them. Overall data quality objectives must be able to justify these added costs.

If the decision is made to complete these increased parameter tests, the laboratory that analyzes the samples needs to know the detection levels and the types of test results required for a comparison to standards and criteria.

Possible goals of conducting biological field studies are (1) to detect differences between biological parameters at the site and those at a reference location, (2) to detect biological contamination, or (3) to quantify risks to humans from contamination of an important food web. It is important that the goals of the study are clearly identified before developing a sample plan. The location and number of sample collection sites, experimental procedures, and analytical techniques are chosen to achieve the goals of the study plan.

Applicable or relevant and appropriate requirements relate primarily to air quality and water quality (EPA, 1985b). Soil standards or criteria have not been determined, although EPA is developing soil cleanup guidance. The levels of soil contaminants that are of concern to ecological systems can be determined by comparing data to background levels or to state or federal cleanup levels or by using a model to determine potential migration levels of soil contaminants into groundwater. Cleanup levels, too, are often based on protection of groundwater systems. In some cases, this criterion may not be totally appropriate, because direct contact with surface or subsurface soils or volatiles can also have an impact on ecosystems.

## 12.6.2 Field Collection Techniques – General

### 12.6.2.1 Field Sampling Program Development

After the pollutants of concern have been identified, their probable transport routes or possible human or biota exposure routes are determined by studying the chemical and physical properties of the pollutant (e.g., octanol/ water partition coefficient, solubility, volatility) and by identifying site characteristics that assist in the transport of the chemicals (e.g., topography, wind, groundwater aquifers, surface water drainages, stormwater runoff patterns).

Important factors for the analysis of general ecological system impacts are (1) frequency and degree of exposure, (2) persistence of the material, (3) substrate composition, (4) geographic location, and (5) sensitivity of the habitat exposed and species present. Additional factors that are important in the aquatic system are water depth, velocity and discharge rate, and range in natural water quality parameters at the time of exposure. Other factors important in analyzing terrestrial system impacts include the physical and chemical nature of soil and the nature of vegetation, especially plant rooting depth.

Once the nature of the contaminants of concern is better understood, the first step is to develop the field study program. Several preliminary activities are necessary in the evaluation of both the general biological and ecological survey to be conducted onsite and the specific field sampling program. These activities include (1) an information search, (2) a preliminary site survey, and (3) identification of site-specific issues of concern.

An initial information search is conducted to identify the following types of data:

- Prior uses of the site including a chronology of events
- Date of last activity onsite
- Any biological and ecological surveys available on the study area and the immediate vicinity
- Species used locally for human consumption and the degree of such usage
- Species most likely present
- The most appropriate sampling method for the species of interest that is also permitted by law
- Appropriate identification keys for species to be sampled
- Background levels of contaminants of concern in soils, water, and biota
- Research on the contaminants of concern as to known effects on local biota or related species

Additional information is obtained on any nearby habitat or any species of special concern such as rare, threatened, or endangered species (both federal and state lists). Possible sources of the above information include state or local game and fishery agencies; conservation agencies; state or local agricultural agencies; and local college or university departments such as the biology, ecology, forestry, or fishery departments. Ecological organizations, museums, Forest Service representatives, the National Park Service, state and local park officials, and local sportsman's clubs may also prove useful.

The second step is a preliminary site survey, which identifies habitat types on and near the site, probable pollutant transport routes, and possible indicator species to serve as the focus of the study.

In preparation for the site survey, the study team prepares a checklist of necessary field gear. The following items can be included in this checklist:

- Site health and safety plan
- Site and vicinity topographic base map (Aerial photographs are valuable in identifying habitat types, but a base map is important for use in the field.)
- Field notebooks
- Camera (Telephoto lenses may be necessary.)
- Collection containers for items such as vegetation or scats
- Appropriate identification keys
- Required personal safety gear
- A summary of important notes collected during the information search

The site survey includes the following types of activities:

- Mapping of vegetation types including areas that are unnaturally denuded
- Mapping of animal tracks, trails, and burrows
- Noting proximity of the site to aquatic or marine habitat
- Noting aquatic habitat type (water temperature, flow, substrate, cover)
- Noting presence of aquatic species (algae, macrophytes, invertebrates, fish)
- Photographing ecological features onsite and in the vicinity

At the completion of these preliminary activities, the project task leader will have sufficient information to determine the type of field sampling program that will most effectively address the site-specific issues of concern. The primary concern is usually possible risk to human health. If human exposure from surface soil contamination is a concern, the staff can conduct a vegetation and small mammal study. Aquatic surveys are important if the site may affect surface waters. Groundwater concerns are generally evaluated through laboratory bioassays, which will be discussed later.

The staff must obtain any collecting permit required by the appropriate regulatory agency before beginning field collection programs.

Field biology and ecology survey data can vary greatly among sites because of differences in species and habitats. Therefore, the U.S. EPA Corvallis Laboratory (Porcella, 1983) is developing a standardized bioassessment protocol for hazardous waste sites. This protocol uses site soils, sediment, and water samples in bioassays on standard organisms such as freshwater fish (fathead minnow), freshwater invertebrates (Daphnids), earthworms (*Eisenia*), freshwater algae (*Selenastrum*), seed germination and root elongation tests, and soil respiration tests. The protocol is currently experimental, and interpretation of the results is not well defined.

These tests are summarized briefly in Subsection 12.6.4.3. This type of standardized bioassessment has been suggested to enable setting priorities for cleanup efforts; more importantly, bioassessment can provide a consistent and relatively inexpensive method for monitoring the effectiveness of any cleanup action.

## 12.6.3 Field Methods – Specific

### 12.6.3.1 Introduction

The field methods, their applications, and their limitations are discussed below. The discussions are grouped by terrestrial, aquatic (freshwater), and near-shore marine environments. Near-shore marine methods are quite similar to many of those discussed for aquatic or freshwater systems and are renamed, but those discussions are not repeated in the marine subsection (12.6.3.4). A parallel description of these methods is discussed in more detail in Appendix A.

The people who collect biological samples at a hazardous waste site must be trained and fully certified to be on that site in accordance with the regulations contained in 29 CFR 1910.120, "Hazardous Waste Operations and Emergency Response; Interim Final Rule," OSHA, December 1986. Depending on the personal protection levels determined for a specific hazardous waste site, the collector may need to modify the field methods to adapt to the dress and equipment requirements of the level of protection. Some personal proctective ensembles will limit the field methods that biologist are physically capable of carrying out. The SM must be made aware of these limitations, and their effects on the project schedule. Also, people planning to collect biota from hazardous waste sites need to be aware of any federal and state endangered species that may be present on the site, as well as having appropriate collection permits as required by the state in which the site is located.

Subsection 12.6.3.2 and Appendix 12A discuss how to collect and process plants and animals before transport to the laboratory. Laboratory methods follow in Subsection 12.6.4.

### 12.6.3.2 Terrestrial Field Methods Summary

VEGETATION

Methods

1. Collection – General

   **Applications:** Collection is useful on any terrestrial site with vegetation; it provides a permanent record of plant species present and any gross morphological abnormalities caused by pollutants. Some perennial woody plants may incorporate a temporal record of pollutant impacts in their structural tissues, either as changes in the chemical composition or in the size of growth rings or shoots. These methods may provide a good qualitative estimate of the size and severity of pollutant impact.

**Limitations:** Collection is not useful on denuded sites; it requires careful comparison against sites that are very similar, but uncontaminated. Finding these "control" sites might be difficult for highly disturbed situations like landfills. Plant stress caused by pollutants at a site might be moderated or aggravated by other site stressors such as low water availability or abnormally high temperature. Variation in response to pollutants between species may require that the response of many species to pollutants be understood if a large number of pollutant sites are to be examined or studied. Unrecognized genetic variation in response to pollutants within a species may cause difficulties. The transitory nature of pollution damage symptoms or of plant species may require multiple site visits at different times of the year to develop a complete picture.

2. Visual

**Applications:** Visiting the site provides a quick, inexpensive assessment of the extent and severity of damage by pollutants. A visit is particularly valuable in scoping out the impacted area when the pollutants are being moved by some physical factor such as wind (downwind) or water (downgradient).

**Limitations:** Seasonal changes in weather, plant morphology, and plant occurrence may necessitate multiple visits to the site during different seasons for the collector to construct an accurate overview of the site. Nonpollutant factors such as plant diseases and drought stress may produce symptoms similar to or identical to pollutant symptoms, obscuring pollutant impacts. Several different pollutants may produce symptoms that are indistinguishable from each other. Small quantities of different pollutants may combine to produce a single symptom in plant population. Data tend to be very subjective and require comparison to similar, but unpolluted, areas or to the subject site before the presence of pollutants at the site.

3. Remote Sensing

**Applications:** Color infrared (CIR) aerial photography can be used on vegetated sites to identify (on a broad scale) those areas that are under stress, possibly from pollutants. CIR can be very useful in defining impacted areas in a general way.

**Limitations:** Many factors other than pollutants can cause stress symptoms in plants (insect infestation, excessively drained pockets of soil, or some diseases), which must be differentiated from pollutant caused symptoms, probably by examination of the area by an experienced person on the ground. Because different species will show different levels of stress from pollutants, interpretation of CIR photos may be difficult unless the site is covered more or less uniformly by one type of vegetation. Optimum time to perform aerial photography is in late summer or early fall; taking CIR photos at other times of the year may be useless because abundant moisture will limit stress in plants. Data tend to be subjective, require comparison to similar unpolluted sites, can be used only on vegetated areas, and may be costly.

4. Ecological Assessments

**Applications:** An assessment is a good technique to collect quantitative data on the species composition and the percentage of groundcover.

**Limitations:** An assessment requires the use of an unpolluted (control) area similar to the one suspected of being polluted. This control area may be either an adjacent unpolluted site, or more rarely, data that were collected from the subject site before the first pollutant impact. Sensitivity of technique depends in large part on the control area being very similar to the treated area. The amount of pollutant cannot be quantified satisfactorily using these techniques; it is useful only on vegetated sites.

5. Tissue Analyses

**Applications:** These analyses are suitable for collecting quantitative data on levels of contaminants in plants growing on polluted sites. The data indicate the extent to which the pollutant may be moving into the animal food web.

**Limitations:** Plants selectively absorb various chemicals or elements from the soil; therefore, plant tissue analysis could give a very poor indication of absolute quantities of a pollutant present on a site. Variation in soil characteristics over a polluted site could markedly affect the quantity of a pollutant present in plant tissues. Normal plant metabolism could chemically alter the pollutant and obscure results of tissue analysis. The amount of pollutant in plant tissue would probably vary among species and possibly among individuals within a species, necessitating the collection of multiple samples per site. Death of pollutant-sensitive species on a site before sampling could result in collection of misleading data. Collections during various seasons may be required for a complete picture.

## VERTEBRATES

### Methods

1. Collection -- General

**Applications:** Collection of terrestrial vertebrates will document the presence of species. Collection techniques can be used to estimate population sizes. Vertebrate collection can be used to gather tissue for pollutant analysis.

**Limitations:** Some vertebrate collection techniques are unsuitable for certain sites (for example, shooting animals near residential areas). Vertebrate collection may generate opposition from animal-rights activists. Some sites might not contain enough animals to ensure statistical validity of the study.

2. Live Trapping

**Applications:** Live trapping can be used for collection of "sensitive species" when lethal traps or hunting would be inappropriate. Population sizes can be estimated using live traps in a "mark-and-recapture" context. A list of species present on the site can be generated. The size of the home range of the species can be estimated either through use of marked and retrapped animals or through radiotelemetry of animals that were trapped alive, marked, and released. Animals can be trapped alive to collect tissue (especially blood) for analysis.

**Limitations:** Humane live trapping can be a very time consuming activity; trappers can be injured by animals that are trapped alive. Successful live trapping requires experienced personnel for trap placement and rapid field identification of species. Trapping may need to conform to local laws on animal capture. Some species are not very susceptible to live-trapping techniques.

3. Lethal Trapping

**Applications:** Lethal trapping can be used to establish which species are present on a site and to collect tissue-donor specimens for analysis of pollutants.

**Limitations:** This method is not suitable for work with "sensitive species" and may agitate animal-rights activists. Lethal traps may cause injury or death to domestic animals on a site and may conflict with local laws or require a special permit. An experienced trapper is required for best results. Proper frequency of checking the traps can make this method extremely time-consuming. Depending on the type of tissue analysis being conducted, tissues of interest may be mangled beyond use during trapping. Some species may not be susceptible to lethal trapping.

4. Hunting

**Applications:** Hunting allows the documentation of species present on the site and is suitable for collecting tissues for analysis. It is most useful on medium- to large-sized species and may be best for species not susceptible to trapping.

**Limitations:** Hunting is impractical for smaller species. It may be a dangerous technique in urban areas where people or property are nearby; hunting may also be illegal or may require special permits. Hunting is not suitable for collecting "sensitive species," is poorly adapted to collection of nocturnal animals, can be a very time-consuming method for collecting certain species, and may result in damage to the tissues being collected for analysis.

5. Ecological Analysis – Habitat Evaluation Procedure (HEP)

**Applications:** HEP provides an integrated analysis of the habitat values on a site. The impact of the pollution on the site's most important habitat values can be assessed by using an uncontaminated comparison area or information on a polluted site before it was polluted.

**Limitations:** A full HEP analysis is a very time-consuming activity. It provides an assessment of impact but does not identify causes of the impact.

### 12.6.3.3 Aquatic (Freshwater) Field Methods Summary

VEGETATION

Some collection techniques discussed for the terrestrial environment can be applied to most freshwater systems. Remote sensing techniques are limited to emergent vegetation or other vegetation on or above the water's surface, which creates a major limitation of this terrestrial technique to freshwater studies. In addition, artificial substrate techniques discussed below for freshwater macroveritebrates can also be used to collect or monitor colonization rates of lower forms of aquatic vegetation.

MACROINVERTEBRATES

Methods

1. Sediment Grabs

**Applications:** Sediment grabs are used in lakes and slower moving rivers and in softer bottoms with invertebrates either in or associated with the sediments down to shallow depths. The grabs can concurrently collect surface sediment for contaminant analyses and characterization.

**Limitations:** Complex gear can be required for deeper water use, and harder sediments require heavier grabs. A boat with a winch may be required in many applications. The use of a boat on a hazardous water body will need to be assessed for human health risks.

2. Core Samplers

**Applications:** Core samplers are used in lakes and slower moving rivers and in softer bottoms where a deeper penetration is required than a grab. Core samplers are needed for bottoms that are harder than a grab can sample and that can be pushed in by hand during shallow water applications. Core samplers can concurrently collect surface and deeper sediments for contaminant analyses and characterization.

**Limitations:** As with grabs, the size of target invertebrates must be considered along with inside barrel diameter of the core and retaining devices in the core mouth. Core samplers (including sophisticated vibracores) can require multiple-ton winch capacities on larger ships to retrieve longer cores.

3. Shovel

**Applications:** Shovels are used for shallow sediment collection in substrate that will stay on the shovel when lifted through shallow water.

**Limitations:** Use of a shovel is qualitative only; very shallow water must be over the sediments. Sediment must be somewhat cohesive to stay on shovel (clays, fine sands); porous gravels or cobbles may allow invertebrates to leave the sample.

4. Box Sieves (used in conjunction with grab, core, and shovel sediment samples)

**Applications:** Box sieves separate invertebrates of interest from sediments collected.

**Limitations:** The choice of screen size determines the size of retained invertebrates; the smaller the screen size the greater the time and cost to process the invertebrate sampled but the better definition of the invertebrates present.

5. Surber Samplers

**Applications:** Surber samplers are used in moving river water to depths less than 12 inches and are best on a bottom that can be disturbed to 2 to 4 inches deep.

**Limitations:** These samplers cannot be used in waters too deep, too slow, or too swift to deploy the gear; the bottom cannot be a solid substrate (rock or very hard clays).

6. Invertebrate Drift Nets

**Applications:** These nets are used in river water moving faster than 0.5 feet per second for invertebrates that migrate or are dislodged from the substrate. The nets can be modified for use in lakes with the net inverted (net opening faces the bottom of lake) to capture vertically migrating invertebrates.

**Limitations:** The nets will not sample species that do not migrate or dislodge from the substrate. Currents can be too swift and may either tear the gear or mutilate the invertebrates sampled, making it difficult to quantify what the samples represent.

7. Other Trawls (The reader should see the fish methods subsection that follows.)

Many larger macroinvertebrates associated with the bottom or near bottom at certain times of the day or night can be collected in conjunction with demersal fish. Applications and limitations discussed in the fish subsection apply.

8. Traps

**Applications:** Traps are used in river or lake bottoms too rough for trawls and for larger macroinvertebrates (i.e., crayfish) that are attracted to bait.

**Limitations:** Traps should be used with mobile macroinvertebrates only. The collector should consider the contaminant content of the bait used to capture animals in traps if the animals are to be used for tissue analyses close to the digestive process.

9. Artificial Substrates

**Applications:** This method is good as a quantitative benthic invertebrate colonization tool and is best for smaller attached or less mobile invertebrate species.

**Limitations:** The method is time consuming; interpretation is more complex if test substrate is not representative of the natural substrate present. This method is not suited to larger, slow-growing, mobile macroinvertebrates.

10. In Situ Bioassays (The reader should see the laboratory tests and analyses in Subsection 12.6.4.)

**Applications:** In situ bioassays are a good toxic challenge or bioaccumulation tool for multiparameter contaminants.

**Limitations:** This method is time consuming for bioaccumulation and requires healthy test invertebrates (crayfish, mussels, etc.) that occur either naturally in the site area (beyond the site's influence) or from other sources (including artificially reared invertebrates) that could inhabit the site area. A cautious assessment of test animal response is required to be certain that noncontaminant-related site parameters (water temperature, low dissolved oxygen (DO), starvation) are not involved. The method lacks control of dependent variables that exist in laboratory bioassay.

11. Miscellaneous (hands, hand tools, dip nets, plankton nets)

**Applications:** Miscellaneous methods have limited gear needs, if at all, and are adaptable to shallow water areas. Diving is presumed unsafe for human health reasons.

**Limitations:** This method is only qualitative, except if fixed-opening nets are metered. The collectors must be gloved or otherwise protected as dictated by site personal protection levels.

12. Tissue Analyses and Species Selection

These methods do not lend themselves to applications and Limitations The investigators must compare the contaminants expected or known on a hazardous waste site with the macroinvertebrates that are likely to be present to decide which may be the best species and tissues to monitor from that species. Local human consumption and tissues consumed must be considered. In many cases, the available aquatic macroinvertebrates to choose from may be quite limited. The same process must be gone through to select a bioassay or bioaccumulation species that is brought into the site. Many aquatic macroinvertebrates are small in size, and whole body samples may be needed. Since different metals and organic chemicals may accumulate in certain tissues in these invertebrates, tissue selection by organ and by pooled samples (if the quantity permits) may yield a higher resolution of what is being accumulated and of what level of risk the bioaccumulation is to the invertebrates that are involved.

## FISH

### Methods

1. Trawls

**Applications:** These methods are used in the flatter, smooth-bottom areas of lakes or ponds or in large, slow-moving rivers. The methods are quantitative if net opening, distance traveled, and gear avoidance by the target species is understood. Other trawls can be modified to fish in midwater or in surface areas for nondemersal fish species.

**Limitations:** The gear can become cumbersome and labor intensive, especially as larger trawls are used and greater boat capacity is required. Gear avoidance in high-visibility water is a problem with larger-sized individuals and with more mobile species. Distance trawled can be difficult to calculate on larger bodies of water; gear is easy to entangle and damage or to lose on bottom obstructions and debris.

2. Electrofishing

**Applications:** This method is quantitative in small confined water bodies that have good in-water visibilitity. Fish can usually be examined and returned without harm. The method is portable for remote applications, if required, and is boat-deployable for larger river or lake applications. Electrofishing is a good choice where bottom type or stream course precludes trawls or seines.

**Limitations:** The method has variable efficiency with conductivity in freshwater or in estuarine (saline) areas. Depending on the gear and settings, electro fishing can be very selective for the size of fish taken. In low-visibility water, capturing stunned fish can be difficult. The method is qualitative in larger water bodies and has added risks to investigators. Behavioral and habitat preference differences among species will influence sampling efficiency. Electro fishing is not effective on very small fish that are in large cobble or rock-type bottoms. Gear efficiency declines with depth in larger bodies of water.

3. Seining

**Applications:** Smoother-bottomed, lower-sloped beaches are suited to this gear. If a person can wade in the area to sample, a seing can be used without a boat, although a boat can be very useful to sample multiple shore areas around some water bodies. Seining gear is compact, easy to store, and easy to use; it is general ly reliable (little risk of loss or great damage).

**Limitations:** Net avoidance can be a problem with some larger individuals and mobile species in higher visibility waters. Seining is semiquantitative in most applications and is difficult to use in faster flowing river areas.

4. Hook and Line

**Applications:** The hook and line method is a simple method if target fish are suited to it. It is a good approach to collect a few larger individuals for tissue analyses (artificial lures rather than bait are preferred). The method is usually better for larger individual fish than smaller fish and is independent of bottom condition, depth, or water current conditions.

**Limitations:** This method is very selective to the fish attracted to the lures or bait used. Investigators may need a license as well as a collector's permit. The hook and line method is not quantitative.

5. Other Fish Collection Approaches

Additional collection approaches that may be adaptable to hazardous waste sites include gill nets, trammel nets, fyke nets, or rotenone. The reader is referred to Nielsen and Johnson (1983) for a discussion of a large number of collection techniques.

6. In Situ Bioassay (The reader should see the laboratory tests and analyses in Subsection 12.6.4.)

**Applications:** In situ bioassay is a good toxic challenge or bioaccumulation tool for multiparameter contaminants that vary in concentration with space and time.

**Limitations:** The bioaccumulation method is time consuming and requires healthy test fish that occur either naturally in the site area (beyond the site's influence) or that could inhabit the site area. The latter type of fish can be obtained from other sources (including fish that are artificially reared) that could inhabit the site area. A cautious assessment of test animal response is required to be certain that noncontaminant-related site parameters (water temperature, low DO, starvation) are not involved. This method lacks control of dependent variables when compared to laboratory bioassay.

7. Tissue Analyses and Species Selection

These methods do not lend themselves to applications and Limitations The investigators must compare the contaminants expected or known on a hazardous waste site with the fish that are likely to be present before deciding which may be the best species and tissues of that species to monitor. Local human consumption and tissues consumed must be considered. In some cases, the available fish species to choose from may be quite limited. The investigators must go through the same process before selecting a bioassay or bioaccumulation species that is brought into the site. Some aquatic (freshwater) fish are small in size, and whole body samples may be a necessity. Since different metals and organic chemicals may accumulate in certain tissues in these fish, tissue selection by organ and by pooled samples (if the quantity permits) may yield a higher resolution of what is being accumulated and what degree of risk the bioaccumulation poses to the fish species involved. The collector should avoid the spawning season when sampling fish species.

The reader should see Appendix 12A for samples of target fish species.

### 12.6.3.4 Marine Field Methods Summary

For near-shore marine studies anticipated in hazardous waste sites, nearly all of the collection and other practices in Subsection 12.6.3.3, Aquatic (Freshwater) Field Methods Summary, can be applied here. In the interest of conserving space, only those methods that require an approach different from approaches listed in the freshwater section will be discussed in this subsection. The reader should refer to the previous subsection for method applications and Limitations Three gear types discussed in the aquatic (freshwater) subsection are not applied in the marine environment (Surber Sampler, Invertebrate Drift Net, and Electrofishing).

Attached or nonmigratory species are best for the investigator to assess, if at all possible; these species allow interpretation of plant and animal condition in the zoned influence of the contaminants reaching the marine environment.

VEGETATION

The reader should see the terrestrial and freshwater discussions (Subsections 12.6.3.2 and 12.6.3.3). In intertidal zones, tidal levels can be used to an advantage in marine vegetation collection and can increase the reliability of remote sensing applications over the limited use of such techniques in freshwater.

MACROINVERTEBRATES

- 1. Sediment Grabs
- 2. Core Samplers
- 3. Shovel
- 4. Box Sieves

In the near-shore zone, tidal levels can be used to eliminate water over sampling areas in the intertidal zone or to reduce water levels in areas beyond the intertidal zone. The size of larger targeted macroinvertebrates in marine sediments must be considered relative to the opening of grabs, especially core samplers and any core-retaining devices.

- 5. Otter Trawls
- 6. Traps
- 7. Artificial Substrates
- 8. In Situ Bioassays

**Limitations:** In addition to limitations for freshwater, fairly protected marine waters would be required to attempt in situ marine bioassays.

- 9. Miscellaneous (hands, hand tools, dip nets, plankton nets)
- 10. Tissue Analyses and Species Selection

FISH

- 1. Trawls
- 2. Electrofishing (not applicable in marine waters)
- 3. Seining
- 4. Hook and Line
- 5. Other Fish Collection Approaches
- 6. In Situ Bioassays

  **Limitations:** In addition to limitations for freshwater, fairly protected marine waters would be required to attempt in situ marine bioassays.

- 7. Tissue Analyses / Species Selection

Several of the field techniques described in Appendix 12A can yield subjective evidence of the impact on biotic systems. Examples of this subjective evidence include unnatural vegetation growth (or lack of growth) and tissue result analyses from an affected area only. While helpful in determining relative risk to humans and natural systems, this type of information is not often defensible because it does not define a statistical basis for impact assessment. Such information can, however, provide another measure for ranking sites relative to other sites. Subjective evidence of harm to natural systems can also provide information on areas of interest that should be included in the physical and biological parameter sampling program.

### 12.6.3.5 Vegetation

Subjective evidence of harm to vegetation (terrestrial, aquatic, and marine) is primarily from visual observation of lack of growth where growth would be expected or of unusual growth of species or specific individuals. For example, *Ulva* is a marine algae susceptible to introduced pollutants. In areas with a high nutrient loading, the Ulva can be excessively abundant. In areas where the composition of pollutants includes hazardous materials, areas can be locally devoid of *Ulva* or of any other algae.

The impact on vegetation is obvious in some areas where spills or leaks have discolored the soil and no vegetation is found. Other areas that appear natural but are devoid of vegetation for extended periods of time indicate possible contamination of soils or water sources. In some cases, field botanists and ecologists can determine harm to the community if the species composition favors tolerant species and if more sensitive species are absent or reduced. Some vegetation, trees in particular, can appear to be unhealthy or dying in a contaminated area.

When the area to be inspected is large, remote sensing can be useful in collecting subjective evidence of harm to biotic systems, as discussed in Subsection 12.6.3.2 and in Section 14, Land Surveying, Aerial Photography, and Mapping. Aerial reconnaissance surveys are common tools in evaluating hazardous waste sites.

### 12.6.3.6 Terrestrial Animals

Compared to vegetation, potential impacts to terrestrial animals resulting from hazardous wastes are much more difficult to subjectively assess in the field. Either a lack of animals and animal tracks in areas expected to support some wildlife or a trapping effort that yields no organisms during the field survey might be indications of an adverse impact. While avoidance behavior in free-ranging populations should not be interpreted without an adequate data base, an absence of wildlife indicates a possible impact on these populations in the vicinity of the site.

Disturbances to wildlife habitats as a result of hazardous waste site operations may suggest impacts to wildlife populations. This disturbance is especially apparent in cases where the waste site is in or adjacent to a sensitive habitat such as a wetland or estuary. In these habitats, there are many opportunities, including high productivity, for wildlife to come in contact with contaminants.

Other subjective assessments of harm to biota can result from cases of animal poisoning, abnormal behavior, or other potential toxic responses reported to local authorities that have occurred in either wildlife species or domestic animals (including pets) found near of the site.

As stated in Subsection 12.6.3, wildlife bioaccumulation data can also be considered subjective because of the possible lack of an adequate reference sample, because of low sample size, and because of a general lack of data amenable to statistical analysis.

#### 12.6.3.7 Aquatic Invertebrates

Subjective field assessment of benthic aquatic invertebrate communities can include evidence of poor water quality or visual observations of an extremely low or extremely high abundance of plants in the system. Subjective evidence of possible harm to aquatic invertebrates would include oil sheens on the water; abnormal water color; or results of water-quality parameter testing that shows low oxygen content, abnormally high salinity or temperature, or extreme ranges in pH.

#### 12.6.3.8 Fish

The same sources of subjective evidence described for aquatic invertebrates can be used to subjectively determine possible harm to fish populations. Additional subjective evidence of an impact on fish populations would include reported fish kills and observations of abnormal growths or tumors in fish caught near the hazardous waste site.

### 12.6.4 Laboratory Tests and Analyses

#### 12.6.4.1 Introduction

Laboratory bioassessment analyses and tests are used to obtain more objective and more detailed information regarding the impact of pollutants on natural systems than would be possible from either the initial subjective biotic field surveys or from chemical testing of site-contaminated soil and water. Laboratory bioassessments include determination of levels of contaminants in organisms that were collected from the site vicinity and in bioassays or toxicity testing using site media, in reference organisms from unaffected areas near the site, or in standard assay organisms.

Bioconcentration and biomagnification tests are conducted when the investigator suspects that an identified food web may be affected by site contaminants. These tests are particularly important if site chemicals are known to bioconcentrate or if the octanol/ water coefficient indicates that a potential for bioconcentration exists. This information is important in the assessment of possible human health risks resulting from the site. Tissues are collected from food web organisms, such as fish or mammals, found on or near the site (Subsection 12.6.2) and analyzed according to laboratory protocol (Subsection 12.6.4.3).

Laboratory bioassays or toxicity tests are used for a variety of reasons including preliminary site screening, monitoring cleanup efforts, or determining the toxicity of complex and/or unusual mixtures of chemicals. An example of a screening test for bioassessment of hazardous waste sites is the experimental protocol being developed by the EPA research laboratory in Corvallis, Oregon. This protocol is composed of a series of tests that use site soils, ground water, surface water, and extracts of site soils to deter mine their respective toxicities to bacteria, algae, seeds, earthworms, aquatic invertebrates, and fish (Porcella, 1983). EPA is assessing the use of this protocol as a standard screening test to establish priorities for site clean ups and as a monitoring tool for cost-effective site clean up. If the procedures for regular analytical testing of site chemicals of concern are expensive and if turnaround time is extensive, some or all of the proposed bioassessment protocol might be used to yield more cost-effective monitoring data.

Toxicity test methods for hazardous waste sites are in the development stage, with no one set of protocols mandated for use. Until some future date when toxicity tests are better established for these sites, investigators must keep up with the developing protocols as discussed above, and they must use existing methods that were designed for other uses. Since most hazardous waste site waters can be characterized as complex effluents, wastewater bioassays can be adapted for use. These techniques are published by EPA and are required to be used in state and regional National Pollutant Discharge Elimination System (NPDES) procedures. Hazardous waste sites that may have (or had) point or nonpoint discharges may have ongoing (or past) bioassays completed by some of these methods. Two recent publications that characterize the present techniques for effluents can be applied to hazardous waste sites (EPA, 1985c and 1985d).

These manuals and other documents referenced in them provide details on methods beyond the developing protocols (Porcella, 1983) that can also be applied to hazardous waste sites.

The most common bioassay or toxicity test currently used is the static acute bioassay using aquatic invertebrates or fish. This test can be used as a quick toxicity screening device or can be employed when chemical analyses indicate the presence of a complex mixture of contaminants. There are often synergisms or antagonisms among the site contaminants that are difficult to describe from available literature or from a comparison to criteria. Bioassays can be important tools in identifying actual toxic responses to the unusual combination of contaminants found onsite. Acute bioassays do not address long-term or chronic toxicity concerns. The reader should see EPA (1985d) for short-term approaches to chronic toxicity issues. Exhibit 12-1 provides recommended species, test temperatures, and life stages for measuring acute toxicity.

Data interpretation of the results of EPA's draft bioassessment protocol can yield an indication of the relative acute toxicity of a specific hazardous waste site based on toxicity criteria (Exhibit 12-2). Low or nondetectable levels of toxicity do not necessarily mean that the site is "safe." Long-term or chronic toxicity is not addressed by this protocol.

Theoretically, hazardous waste sites can be compared by this protocol if the study plans are designed to incorporate randomness in sample collection and to minimize the variability of site-specific characteristics. Ultimately, the protocol is aimed at allowing EPA to rank hazardous waste sites for cleanup priority and to monitor the cleanup efforts to more effectively protect human life and natural systems.

### 12.6.4.2 Test Material Handling Requirements

#### 12.6.4.2.1 Collection Techniques

As described in Subsection 12.6.2, types of biotic test materials collected from sites can include vegetation, aquatic invertebrates, tissues from terrestrial animals, and whole fish or tissues from fish. Approximately 30 grams of vegetative material and 100 grams of animal tissue are needed to run most tissue

## Exhibit 12-1
## RECOMMENDED SPECIES, TEST TEMPERATURES, AND LIFE STAGES

| Species | | Test Temperature[a] (°C) | Life Stage[b] |
|---|---|---|---|
| Freshwater | | | |
| Vertebrates | | | |
| Cold Water | | | |
| Brook trout | *Salvelinus fontinalis* | 12 | 30 to 90 days |
| Coho slamon | *Oncorhynchus kisutch* | 12 | 30 to 90 days |
| Rainbow trout | *Salmo gairdneri* | 12 | 30 to 90 days |
| Warm Water | | | |
| Bluegill | *Lepomis macrochirus* | 20 | 1 to 90 days |
| Channel catfish | *Ictalurus punctatus* | 20 | 1 to 90 days |
| Fathead minnow | *Pimephales promelas*[c] | 20 | 1 to 90 days |
| Invertebrates | | | |
| Cold Water | | | |
| Stoneflies | *Pteronarcys spp.* | 12 | Larvae |
| Crayfish | *Pacifastacus leniusculus* | 12 | Juveniles |
| Mayflies | *Baetis* spp. or *Ephemerella* spp. | 12 | Nymphs |
| Warm Water | | | |
| Amphipods | *Hyalella,* spp., | 20 | Juveniles |
| | *Gammarus lacustris, G. fasciatus,* | 20 | Juveniles |
| | or *G. pseudolimnaeus* | 20 | Juveniles |
| Cladocera | *Daphnia magna* or *D. pulex,*[d] | 20 | 1 to 24 hours |
| | *Ceriodaphnia* spp. | 20 | 1 to 24 hours |
| Crayfish | *Orconectes* spp., *Cambarus* spp., | 20 | Juveniles |
| | *Procambarus* spp., | 20 | Juveniles |
| Mayflies | *Hexagenia limbata* or *H. bilineata* | 20 | Nymphs |
| Midges | *Chironomus* spp. | 20 | Larvae |
| Marine and Estuarine | | | |
| Vertebrates | | | |
| Cold Water | | | |
| English sole | *Parophrys vetulus* | 12 | 1 to 90 days |
| Sanddab | *Citharichthys stigmaeus* | 12 | 1 to 90 days |
| Winter flounder | *Pseudopleuronectes americanus* | 12 | Post-metamorphosis |

## Exhibit 12-1
## (continued)

| Species | | Test Temperature[a] (°C) | Life Stage[b] |
|---|---|---|---|
| Warm Water | | | |
| Flounder | *Paralichthys dentatus* | 20 | 1 to 90 days |
| | *P. lethostigma* | 20 | 1 to 90 days |
| Longnose killifish | *Fundulus similis* | 20 | 1 to 90 days |
| Mummichog | *Fundulus heteroclitus* | 20 | 1 to 90 days |
| Pinfish | *Lagodon rhomboides* | 20 | 1 to 90 days |
| Sheepshead minnow | *Cyprinodon variegatus* | 20 | 1 to 90 days |
| Silverside | *Menidia* spp. | 20 | 1 to 90 days |
| Spot | *Leiostomus xanthurus* | 20 | 1 to 90 days |
| Threespine stickleback | *Gasterosteus aculeatus* | 20 | 1 to 90 days |
| Invertebrates | | | |
| Cold Water | | | |
| Dungeness crab | *Cancer magister* | 12 | Juvenile |
| Oceanic shrimp | *Pandalus jordani* | 12 | Juvenile |
| Green sea urchin | *Strongylocentrotus droebachiensis* | 12 | Gametes/embryo |
| Purple sea urchin | *S. purpuratus* | 12 | Gametes/embryo |
| Sand dollar | *Dendraster excentricus* | 12 | Gametes/embryo |
| Warm Water | | | |
| Bluecrab | *Callinectes sapidus* | 20 | Juvenile |
| Mysid | *Mysidopsis* spp. | 20 | 1 to 5 days |
| | *Neomysis* spp. | 20 | 1 to 5 days |
| Grass shrimp | *Palaemonetes* spp. | 20 | 1 to 10 days |
| Penaid shrimp | *Penaeus setiferus* | 20 | Post larval |
| | *P. duorarum* | 20 | Post larval |
| | *P. aztecus* | 20 | Post larval |
| Sand shrimp | *Crangon* spp. | 20 | Post larval |
| Pacific oyster | *Crassostrea gigas* | 20 | Post larval |
| American oyster | *Crassostrea virginica* | 20 | Embryo/larval |

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[a] To avoid unnecessary logistical problems in trying to maintain different test temperatures for each test organism, it would be sufficient to use one tenperature (12°C) for cold water organisms and one temperature (20°C) for warm water organisms.

[b] The optimum life stage is now known for all test organisms.

[c] In tests with nine toxicants, Mayes et al. (1983) found no significant difference in the sensitivity of fish ranging in age from 10 to 100 days.

[d] *Daphnia pulex* is recommended over *D. magna* because it is more widely distributed in the United States, test results are less sensitive to feeding during tests, and it is not as easily trapped on the surface film.

Source: EPA (1985c).

## Exhibit 12-2

## DEFINITION OF TOXICITY CATEGORIES FOR AQUATIC AND TERRESTRIAL ECOLOGICAL ASSAYS

| Assay | Activity Measured | Sample Type[a] | MAD[b] | Units | Response Levels for $LC_{50}$ or $EC_{50}$ Concentrations[c] | | |
|---|---|---|---|---|---|---|---|
| | | | | | High | Moderate | Low or Not Detectable |
| Freshwater Fish | 96-hr $LC_{50}$ (lethality) | S | 1 | g/1 | <0.01 | 0.01-0.1 | 0.1-1 |
| | | L | 100 | percent | <20 | 20-75 | 75-100 |
| Freshwater Invertebrate | 48-hr $EC_{50}$ (immobilizition) | S | 1 | g/1 | <0.01 | 0.01-0.1 | 0.1-1 |
| | | L | 100 | percent | <20 | 20-75 | 75-100 |
| Freshwater Algae | 96-hr $EC_{50}$ (growth inhibition) | S | 1 | g/1 | <0.01 | 0.1-0.1 | 0.1-1 |
| | | L | 100 | percent | <20 | 20-75 | 75-100 |
| Seed Germination and Root Elongation | 115-hr $EC_{50}$ (inhibited root elongation) | L | 100 | percent | <20 | 20-75 | 75-100 |
| Earthworm Test | 336-hr $LC_{50}$ | S | 500 | g/kg | <50 | 50-500 | 500 |
| Soil Respiration Test | 336-hr $EC_{50}$ | S | 500 | g/kg | <50 | 50-500 | 500 |
| | | L | 100 | percent | <20 | 20-75 | 75-100 |

[a] S = solid, L = aqueous liquid, includes water samples and elutiate or leachate. Nonaqueous liquids are evaluated on an individual basis because of variations in samples, such as vehicle, percent organic vehicle, and percent solids.

[b] MAD = Maxium applicable dose.

[c] $LC_{50}$ = Calculated concentration expected to kill 50 percent of population within the specified time interval.

$EC_{50}$ = Calculated concentration expected to product effect in 50 percent of population within the specified time interval.

Source: Porcella, 1983

analyses (EPA, 1980b and 1980c). Surface soils, groundwater, sediment, and surface waters are collected to run bioassay types of tests.

Initial screening bioassays are usually performed using site soils collected from three sample sites: one at the point of greatest contamination, one at the boundary of the hazardous waste site, and one from a reference or control area. If the boundary-site contamination level is found to be higher than the control, additional offsite samples are taken to identify the contaminant boundary. Additional screening bioassays can be run using onsite or near-site surface water or groundwater.

Surface soils and sediments from the site are collected according to the protocol as described in other sections (Sections 8 and 10) of this compendium. Typically, three subsamples of soil are collected from the top one-half meter of depth in a square meter area at the desired sample location and are thoroughly mixed. The size of the sample depends on the test being performed. Soil and sediment samples are sampled and stored according to procedures described in other sections (Sections 6, 8, and 10) of this compendium.

Groundwater and surface waters are also collected and handled according to procedures described in other sections (Sections 6, 8, and 10) of this compendium. The size of the sample depends on the test being performed.

### 12.6.4.2.2 Laboratory Techniques

#### Sample Storage

Biological samples, including fish and mammal tissues frozen in the field, are stored in a designated freezer until extracted. The biological samples should be stored separately from other samples. Water and soils / sediments that were collected from the site and are to be used in bioassays are stored on ice during shipment and are kept at 4°C until testing begins. The temperature of the stored water sample is allowed to equilibrate to that of the bioassay test temperature before being diluted. All samples are labeled and kept in designated storage areas. If sample jars are breakable, outer unbreakable containers are used to transport samples to the test area.

#### Equipment Cleaning

Test containers are primarily made of glass, No. 316 stainless steel, and perfluorocarbon plastics. Each test container is cleaned as follows:

1. Wash with nonphosphate detergent.

2. Rinse with distilled water.

3. Rinse with 100 percent acetone. If volatile analyses are required, acetone use is discouraged and methanol is often used as a substitute.

4. Rinse with distilled water.

5. Rinse with nitric acid (5 percent).

6. Rinse thoroughly with distilled water.

7. Rinse finally with distilled, deionized, or organic-free water (three times), as appropriate to required analyses.

### 12.6.4.3 Specific Tests and Analyses

#### 12.6.4.3.1 Vegetation

Tissue Analysis

Before plant tissues are analyzed, samples need to be prepared for the type of analysis being done. If airborne sources of contamination are suspected, it may be necessary to wash all samples before analysis. Washing will remove loose surface contaminants and provide for an analysis of tissue concentrations. If surface contamination data are required, samples are not washed. Roots are thoroughly washed because of the possibility that contaminants could be adsorbed to soil particles and not to root tissue.

Samples are weighed before washing to determine weight gain as a result of water absorption. Plant material to be analyzed is washed slowly in distilled or deionized water. The material is gently moved in the water and is not scrubbed. Detergents are not used. Washed material is placed on clean blotter paper and is not allowed to air dry. Each sample is prepared for analysis immediately following washing.

The laboratory also analyzes a sample of the clean wash water, of the wash water after washing plants, and of a piece of the blotter paper.

Vegetative samples are homogenized through mincing, grinding, or blending. For nonvolatile contaminant analyses, these plant tissues can be dried and then processed through a Wiley mill or other tool as appropriate to the analyses planned. For volatile contaminant analyses, these plant tissues need to be processed "wet" with no drying during the analytical process. In this situation, a separate sample is dried for measurement of wet and dry weight ratios and is not used in the volatile analyses.

The amount and types of planned analyses dictate the required sample size of plant tissue. In most cases, 30 grams (wet weight) will suffice, although many different types of analyses may require a larger amount of plant material. If the investigator anticipates that an organic contaminant is very dilute in plant tissues, large quantities of the plant tissue may have to be collected and subjected to extraction procedures before achieving the required analytical result. For nonvolatile analyses, 1 gram (dry weight) of plant tissue is often used.

For the most part, "standard methodology" does not currently exist for plant (or animal) tissue analyses. Methods originally designed for water or sediment will usually address plant tissue analyses; however, the sample preparation process is not included. In some cases, the analytical technique or the interpretation of gained results must be modified because of matrix-related interferences and other tissue problems not encountered in water and sediment testing. Pesticides are well covered in the EPA 1980d manual. In other cases, modified water or sediment analytical techniques exist in an "interim" or "draft" status that may cover only a subset of the required analyses.

Because of the current lack of a standard methodology for plant tissue analyses, the reader should contact the regional EPA laboratory for the latest available plant tissue processing and analytical chemistry techniques for the contaminants of concern. The Information sources subsection lists several EPA methods manuals that can provide some assistance, including EPA 1980b, 1980c, 1980d, 1982, and 1983.

### Seed Germination and Root Elongation Bioassay

Toxic substances that inhibit plant germination or root elongation (often the most sensitive phase in plant growth) can decrease primary productivity, reduce crop yields, and change natural systems by selection for tolerant species. A brief description of this test is provided below. For additional details, the reader should see Porcella (1983). Although inhibition of both seed germination and root elongation is an observable toxic response, root elongation inhibition is more likely at lower concentrations and is a preferred end point in this bioassay.

Untreated seeds (i.e., seeds not treated with fungicide, other pesticides, or fertilizers) can be obtained from commercial seed companies, state agricultural experiment stations, and U.S. Department of Agriculture laboratories. Seeds are sized and individually examined, and tests are conducted using the most common size of seed.

Five test species representing commercially important and different plant families are used in this assay: lettuce (butter crunch), *Lactuca sativa L.*; cucumber (hybrid Spartan valor), *Cucumis sativa L.*; red clover (Kenland), *Trifolium praetense L.*; wheat (Stephens), *Triticum aestivum L.*; and radish (Cherry Belle), *Raphanus sativa L.*

Equipment needed to conduct this assay includes one-piece molded glass tanks (6-liter capacity) outfitted with glass pegs or rods to hold at least five glass plates at a 67-degree angle, a spray bottle with a fog or mist nozzle, a metric ruler, forceps, a Soxhlet extraction apparatus, Whatman No. 3 mm chromatography filter paper, single-ply cellulose tissues (e.g., Kimwipes), a triple-beam balance, a pH meter, storage bottles, and plastic bags to enclose the test tanks (described above).

The test medium is an extract of a solid sample and is prepared according to the procedure listed in Exhibit 12-3. Dilutions of the extract should be made with distilled water, which is used as a negative control. The plate is then placed in the test chamber along with enough test medium solution to immerse by 2 to 3 centimeters the bottom of the test plate and filter paper (500 milliliters). This procedure is repeated for each plant species in the test. The whole chamber is enclosed in a plastic bag to maintain a humid atmosphere and is placed in a dark, temperature-controlled area at 252°C for 115 hours. Extracts should be tested for pH and salinity. Generally, pH $>6.5$ and salinity $<0.01$ N salt will not be toxic. If the medium is outside these ranges, an artificial control should be assayed.

A filter paper is soaked in the test medium, and then 15 seeds are placed on the test paper. A narrow strip of previously cleaned (using the Soxhlet extraction apparatus) cellulose tissue is placed over the seeds and misted to cause the tissue to adhere.

The plate is then placed in the test chamber along with enough test medium solution to immerse by 2 to 3 centimeters the bottom of the test plate and filter paper (500 milliliters). This procedure is repeated for each plant species in the test. The whole chamber is enclosed in a plastic bag to maintain a humid atmosphere and is placed in a dark, temperature-controlled area at 25 ± 2°C for 115 hours.

Each assay is composed of a tank for each test concentration, positive controls, and negative (distilled water) controls. The concentration range of NaF used for the positive control that causes an $EC_{50}$ (effective concentration causing inhibition of 50 percent of growth compared to control) for each seed species is radish, 400 to 500 mg NaF/liter; wheat, 300 to 400 mg NaF/liter; lettuce, 100 to 200 mg NaF/liter; cucumber, 150 to 200 mg NaF/liter; and red clover, 80 to 100 mg NaF/liter.

Seeds and roots must be examined and measured at 30 minutes from the end of the 115 hours to have a valid test. The root length is measured from the transition point between hypocotyl and root to the tips of the root. At the transition between the hypocotyl and the primary root, the axis may be slightly swollen,

## Exhibit 12-3
## METHODS FOR PREPARING SOIL EXTRACT

**Steps**

1. Weigh an adequate amount of air-dried soil sample for all desired tests.

2. Add a weight of distilled water equal to four times the soil weight.

3. Shake for 48 hours (150 rpm) at constant temperature (20 ± 2°C) in the dark.

4. Allow to settle, decant, and filter with 0.45 μm membrane to obtain the extract. Soil sample extracts with high clay content will have to be centrifuged and decanted before filtration.

5. Relate all extracts to the original weight of soil. Measure volume of extract and relate to initial soil weight. For example, if 3,100 ml of extract is obtained from 1,000 grams of air-dried soil, there are 3.1 ml/gram of soil. Then, if 25 ml of extract are added to 100 grams of soil for a test, this combination would be equivalent to 8 grams of soil (25/3.1) or a 7.4 percent soil solution (8/108). This soil solution would be the highest concentration. For a geometric series of tests, subsequent samples would be decreased by halves. For example, for 7.4, 3.7, 1.85,... the percent extract plus sample volumes would be 25 + 0, 12.5 + 12.5, 6.25 + 18.75, ....

6. Do not concentrate extracts; extracts should be prepared within 24 hours of collection. Extracts should be checked for salinity using conductivity.

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Source: Porcella, 1983.

may contain a slight crook, or may change noticeable in size for the radish, lettuce, cucumber, and red clover. In wheat, the single longest primary or seminal root is measured from the point of attachment to the root tip.

A range-finding test that consists of one control tank and one test tank each of 100, 10, 1, 0.1, and 0.01 percent extract is conducted to see if a definitive test is necessary. If the 100 percent tank has mean root lengths that are 65 percent of control and if at least 10 of the 15 seeds germinate, no further testing, examination, or root measurement is done. No $EC_{50}$ is possible with these results. If a definitive test is called for, at least six extract concentrations must be chosen in geometric series; the highest concentration used will be the next higher concentration than that concentration which reduced the mean root length to less than 50 percent of the control.

## Freshwater Algae 96-Hour Test

Unicellular algae are important primary producers in aquatic food webs and are often sensitive to environmental changes. Algal growth can be either inhibited or stimulated in the presence of contaminants. In EPA's Corvallis laboratory, the bioassessment protocol includes a simple screening test to be conducted in 96 hours for freshwater algae. This 96-hour screening test exposes algae to various concentration of test material and growth (measured by cell counts or other methods listed below). Typical results of this test are reported as $EC_{90}$ and $EC_{50}$ if growth is inhibited or as $SC_{20}$ if growth is stimulated. ($EC_{50}$ is the lowest test concentration causing growth inhibition of 50 percent relative to control. $SC_{50}$ is the lowest concentration causing growth stimulation of 20 percent relative to the control.)

The proposed test species is *Selenastrum capricornutum*, a nonmotile chlorophyte that is easily maintained in laboratory cultures. The test algae is kept in flasks containing standard Algal Assay Medium (AAM) in a constant-temperature room or incubator at 24 ± 2°C (from Miller et al., 1978, as reported by Porcella, 1983). Exhibit 12-4 lists nutrient components of the AAM. Continuous illumination of 4300 ± 430 lumens/$m^2$ (400 ft-c) is required, and overhead cool-white fluorescent bulbs are recommended. The algal culture is checked microscopically to ensure that the culture is healthy and is composed only of the test algae. The concentration of cells at the beginning of the test should be approximately 10,000 cells/ ml.

According to Porcella, test material can be aqueous liquids (groundwater, surface water, or soil extracts in water); nonaqueous liquids (aqueous samples with greater than 0.2 percent organics, nonaqueous liquids, solvent exchange samples, and extracts or leachates in a nonaqueous or organic vehicle); or solids. Nonsolid test material should be filtered (preferably onsite) using a 0.45-micrometer cellulose acetate filter to remove indigenous algae. The minimum sample size needed to run the algae test is 1 gram of soil (or solid material), 0.06 liter of aqueous liquid, or 0.05 liter of nonaqueous liquid. Test material is obtained from areas specified in the study plan by using standard collecting methods.

Preliminary tests are run with 100 percent test material with and without nutrients contained in the AAM. If the 100 percent test with nutrients shows a less than 50 percent inhibition compared to a control sample, the material is considered relatively safe and no further testing is done. If there is a greater than 50 percent inhibition, test material should be assayed by either a range-finding test (dilutions of 80 percent, 10 percent, 1 percent, and 0.1 percent using three replicates each) or a definitive test, or both. A definitive test is conducted after a range-finding test by spanning the moderate response concentration using a geometric series. For example, if 1 percent (0.01) and 10 percent (0.10) gave toxic responses, the definitive test series would include 0.1, 0.05, 0.025, 0.0125, 0.00625, and 0.003125. All tests are conducted with nutrients added essentially equivalent to 100 percent AAM, with AAM used to make dilutions.

Controls include the AAM (negative control) to check standard organism response; the receiving water, if applicable (reference control); and a solvent control, if applicable (dilution water plus solvent). The positive control is applied with $ZnCL_2$ in AAM at a concentration of 80 mg $Zn^{++}$/1 to give a range of inhibition of 51 to 66 percent (long-term mean = 58.8).

## Exhibit 12-4
## COMPOSITION OF ALGAL ASSAY MEDIUM (AAM)

### Macronutrients
### Nutrient Composition

| Stock Solutions* | | Prepared Medium | |
|---|---|---|---|
| Compound | Concentration (g/1) | Element | Concentration (mg/1) |
| $NaNO_3$ | 25.500 | N | 4.200 |
| $NaHCO_3$ | 15.000 | Na | 11.001 |
| $K_2HPO_4$ | 1.044 | C | 2.143 |
| | | P | 0.186 |
| $MgSO_4 \cdot 7H_2O$ | 14.700 | S | 1.911 |
| $MgCl_2 \cdot 6H_2O$ | 12.164 | Mg | 2.904 |
| $CaCl_2 \cdot 2H_2O$ | 4.410 | Ca | 1.202 |

### Micronutrients
### Nutrient Composition

| Stock Solutions* | | Prepared Medium | |
|---|---|---|---|
| Compound | Concentration (g/l) | Element | Concentration (mg/1) |
| $H_3BO_3$ | 185.520 | B | 32.460 |
| $MnCl_2 \cdot 4H_2O$ | 415.610 | Mn | 115.374 |
| $ZnCl_2$ | 3.271 | Zn | 1.570 |
| $CoCl_2 \cdot 6H_2O$ | 1.428 | Co | 0.354 |
| $CuCl_2 \cdot 2H_2O$ | 0.012 | Cu | 0.004 |
| $Na_2MoO_4 \cdot 2H_2O$ | 7.250 | Mo | 2.878 |
| $FeCl_3 \cdot 6H_2O$ | 160.000 | Fe | 33.051 |
| $Na_2EDTA \cdot 2H_2O$ | 300.00 | | |

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* Other forms of the salts may be used as long as the resulting concentrations of elements are the same.

Source: Porcella, 1983, from Miller et al., 1978.

After 96 hours of exposure, algae growth is measured by any one of the following methods: electronic particle counting, biomass (dry weight), absorbance (as measured by a spectrophotometer), or microscopic counting. Electronic particle counting is preferred, but cursory microscopic examination is important to identify abnormal cell shape or condition.

Exhibit 12-5 contains a summary of the possible methods used in counting cells, the equipment used, and the appropriate format used for results.

The investigator must use the definitive test to obtain data to calculate the $EC_{50}$, $EC_{90}$, or $SC_{20}$ and should assay a minimum of four test concentrations. The $EC_{50}$, $EC_{90}$, and $SC_{20}$ are calculated using any of several statistical methods. Exhibit 12-2 lists the toxic categories for results of the freshwater algal 96-hour test (Porcella, 1983).

#### 12.6.4.3.2 Terrestrial Animals

Laboratory tests and analyses pertinent to terrestrial animals include bioaccumulation and biomagnification analyses that are performed on vertebrate tissues taken from animals collected on or near the study site. The analyses also include laboratory assays of toxicity of soils and soil extracts to invertebrates (i.e., earthworms).

#### Bioaccumulation and Food Web Transfer Tests

Laboratory protocols for determining the presence of pesticides and related compounds in tissue and blood samples are contained in the information sources under Sherma (1976). An additional reference containing protocols for determining other contaminants in tissue is EPA 1980d.

In general, tissues to be analyzed are collected and stored in glass jars or vials with foil- or Teflon-lined screw caps and are either refrigerated (if analyses will be conducted within 24 hours) or frozen. The amount of tissue needed depends on the expected degree of contamination and the detection levels required for data interpretation. If low concentrations are expected, more tissue will be needed. If the degree of contamination is unknown, 100 grams of tissue is the typical amount collected. Specific procedures for the extraction of pesticides and their residues will vary. Solvents range from hexane or petroleum ether for nonpolar organochlorine and organophosphorus compounds to methylene chloride for polar carbamates. Some prior knowledge of the pesticides of concern is necessary in determining the laboratory methodology to be used. Details of these methodologies are contained in previously cited references.

Briefly, tissue samples are broken down into small pieces and blended before extraction. In most cases, the Soxhlet extraction method is used. High-performance liquid chromatography is EPA's recommended technique for the separation and analysis of complex mixtures (Sherma, 1976). However, gas or column chromatography is also used. Thin layer chromatography can be used to confirm residues following initial screening and quantification by gas chromatography.

#### Earthworm Toxicity Test

In EPA's laboratory in Corvallis, the bioassessment protocol includes a two-phase test involving the earthworm *Eisenia foetida*. The reader should contact the regional EPA laboratory to obtain the current status of this procedure and a source for this earthworm. Although it is not common, this earthworm is regularly used in testing, grows easily in organic soils (commonly found in sewage beds), has a short life cycle, and readily reproduces. The proposed tests closely approximate actual conditions encountered by earthworms and do not require elaborate equipment or extensive personnel training.

## Exhibit 12-5
## ALGAE ASSAY PROCESSING METHODOLOGIES

| Method | Equipment/Procedure | Resulting Data Format |
|---|---|---|
| Electronic Particle Counting | Model ZB1 Coulter Counter with Mean Cell Volume (MCV or MHR) computer | mg dry weight *S. Capricornutum*/liter or<br>Number of *S. Capricornutum* cells/liter |
| Biomass | Measured portion of algal suspension filtered with tared 0.6 micrometer PVC membrane filter-dried for 2 hours at 70°C--cool in desiccator weighed. Test culture volume filtered and handled same. Subtract tare weight and divide by volume of culture filtered | mg/liter dry weight |
| Absorbance | Spectrophotometer or colorimeter at wave-length of 750 nm with optical density greater than 0.05 and less than 1.0 | Absorbance units per mg dry weight per liter |
| Microscopic Counting | Hemacytometer counting chamber and microscope | cells/liter |

The calculations used to interpret data results are as follows:

$$\frac{(T\text{-}IN) - P\,(C\text{-}IN)}{P(C\text{-}IN)} \times 100 = \begin{matrix}(+)\,\% = \text{Stimulation} \\ (-)\,\% = \text{Inhibition}\end{matrix}$$

where:
P = percent volume of AAM used to dilute test sample (≥ 20 percent)
T = maximum standing crop (mg/l) in test sample
IN = dry weight (mg/l) of inoculum at start of test
C = maximum standing crop (mg/l) in AAM control

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Source: Porcella, 1983.

Briefly, the first phase of the test is a simple contact test where individual worms are exposed to various concentrations of soil extracts on filter paper. The second phase exposes earthworms to actual test soils or to extracts in a defined soil medium. The contact test consists of a range-finding and definitive test, while the soil test is usually just definitive. The end point of these definitive tests is an $LC_{50}$, with worms classified as dead when they do not respond to a gentle mechanical stimulus to the anterior end.

The first earthworm test is the range-finding contact test where individual worms are placed in vials lined with filter paper (Whatman Grade 1) soaked in varying concentrations of extracts and a negative control (distilled water). Extracts are prepared as described in Exhibit 12-3. Dilutions used in this preliminary test are 100 percent, 10 percent, and 1 percent. Ten replicate test vials for each dilution are laid on their sides in a dark, temperature-controlled area (20 ± 2°C) for 48 hours. The number of dead worms is counted at the end of the test and compared to the control tests.

A geometric dilution series is used in the definitive contact test, with the concentrations used determined by the results of the range-finding test. A positive control is run using 0.354 mg Cu/liter of copper sulfate. This concentration will provide a response range of 0.9 to 1.1 of the $LC_{50}$. A negative control is also run. Test procedures are the same as for the range-finding tests.

Earthworm toxicity tests using soils are conducted in two ways: one with artificial soil to which test soil extract is added in varying concentrations, and a second in which test soil is used directly and "diluted" with artificial soil. Artificial soil is made of three general constituents: 70 percent industrial sand, 20 percent Kaolinite clay, and 10 percent sphagnum peat. Exhibit 12-6 provides a detailed list of two of these components. Calcium carbonate is used to adjust the pH to 7.0. The moisture content is adjusted to approximately 20 percent of dry weight with either test extract and/or distilled water. Site soil is prepared using the procedure outlined in Exhibit 12-7.

Test containers are 500-ml crystallizing dishes covered with plastic lids, petri dishes, or plastic film. In each dish, 400 grams of moist test medium are used. For each test, four replicates of each concentration are run on 10 test worms. Four negative controls (distilled water) and one positive control, containing copper sulfate at a concentration of 600 mg Cu/kg of soil, are also run for each test. Test containers are held at a constant temperature (20 ± 1°C) in a continuously lighted area for 14 days. The average weight of the test and control worms is determined at the beginning and at the end of each test. Again, mortality is determined by sorting the worms from the soil and recording their reaction to mechanical stimulation.

An assessment of mortality at 7 days and continuation of the test to 28 days is optional. However, soil moisture may need to be adjusted because moisture is lost during sorting.

Test results are plotted on log probit graph paper and the median lethal concentration ($LC_{50}$) and its confidence limits are estimated. The $LC_{50}$ values are given as percent of test soil sample. Mortality in the negative controls should not exceed 10 percent. If some mortality does occur (< 10 per cent), a correction is made using the following formula: Corrected mortality percent = (observed mortality percent - control mortality percent)/100 - control mortality.

### Acute Toxicity Test

The acute toxicity test is a standard test that is commonly used to describe the toxicity of a compound or mixture of compounds to aquatic systems. *Daphnia* is the most common freshwater organism used. However, many crustaceans, mollusks, and fish have been used. The following is a brief description of the acute-static toxicity test used as a part of the EPA's bioassessment protocol.

The daphnid, *Daphnia magna*, was the basis for much of the preliminary work in acute toxicity testing as described by Porcella (1983). EPA (1985c) now recommends *D. pulex* over *D. magna* because the former

## Exhibit 12-6
## COMPONENTS OF ARTIFICIAL SOIL

### General Composition by Weight

1. 70% Industrial Sand
2. 20% Kaolinite Clay
3. 10% Sphagnum Peat

### Specific Composition

### 1. Industrial Sand

| Diameter in Microns | Percent |
|---|---|
| 45 | 1.7 |
| 45 | 9.3 |
| 63 | 29.0 |
| 90 | 34.3 |
| 125 | 20.8 |
| 180 | 4.0 |
| 250 & greater | 0.8 |

### 2. Kaolinite Clay

| Composition | Percent |
|---|---|
| $SiO_2$ | 58.5 |
| $TiO_2$ | 1.3 |
| $AL_2O_3$ | 28.0 |
| $Fe_2O_3$ | 1.0 |
| MgO | 0.3 |
| CaO | 0.2 |
| $K_2O$ | 2.0 |
| $Na_2O$ | 0.3 |
| loss on ignition | 8.4 |

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Source: Porcella, 1983.

## Exhibit 12-7
## PROCEDURE FOR HOMOGENIZING SOIL SAMPLES

1. Air dry the soil to be tested. (Air drying is considered completed when an aliquot of soil has no more weight loss.)

2. Add 25 burundum cylinders and about 2 liters of air-dried soil to a ball mill.

3. Mill about 5 minutes (until soil is coffeeground size). Then sieve through a 2mm-mesh sieve.

4. Return larger particles to the ball mill, and repeat steps 2 through 4 until the sample is completely ground with the exception of rocks. Discard rocks.

5. Before use, thoroughly homogenize soil using a laboratory or small cement mixer.

6. Clean the ball mill by adding 1 quart of silica sand and 10 burundum cylinders. Mill for 15 minutes, discard, and then brush out mill.

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Sources: Lighthart, 1980; unpublished procedures as reported by Porcella, 1983.

species is "more widely distributed in the United States, test results are less sensitive to feeding during tests, and it is not as easily trapped on the surface film." *D. pulex* is, therefore, preferred in these studies, if available.

EPA's test uses early instars of *Daphnia* in a static type of assay (i.e., the same body of water is used throughout the test as compared to a flow-through test in which the water is replaced). The exposure time is 48 hours, and because death is not always easily determined in *Daphnia*, .e test results are given as effective concentration (48-hour $EC_{50}$). A summary of test conditions for the *Daphnia* acute test is presented in Exhibit 12-8.

It should be noted that static bioassay has a limited application for compounds that become volatile or undergo rapid chemical change in water.

Dilution water can be water from the site (upstream of possible contamination), local dechlorinated tap water, or reconstituted water, as long as it can support healthy organisms for the duration of the test procedure without having the organism show any sign of stress. The water chosen for dilution water is tested to ascertain that none of the following substances exceeds the maximum allowable concentration as shown:

| Pollutants | Maximum Concentration |
|---|---|
| Suspended solids | 20 mg/l |
| Total organic carbon | 10 mg/l |
| Unionized ammonia | 20 µg/l |
| Residual chlorine | 3 µg/l |
| Total organophosphorus pesticides | 50 µg/l |
| Total organochlorine pesticides plus PCBs | 50 µg/l |

Other water quality considerations are pH, hardness, temperature, alkalinity, and conductivity.

The test animal, *Daphnia*, was chosen because of its wide geographic distribution, importance in the food web, temperature requirements, wide pH tolerance, ready availability, and ease of culture. *Daphnia* is obtained from laboratory cultures in its early instar stages (less than 24-hour neonites), and each test is conducted using organisms that are from the same source and that are as healthy and uniform in size and age as possible. Care is taken to maintain the cultures in as ideal a situation as possible. Avoidance of stress and disturbances is important.

Unless the approximate toxicity of the sample material is already known, a minimum of six concentrations of test material should be prepared, with the maximum concentration being the maximum applicable dose (MAD) for that sample type (see Exhibit 12-2). Test organisms are placed in test vessels no later than 30 minutes after test solutions are prepared.

#### 12.6.4.3.3 Fish

Fish, especially those species consumed by humans, are common test organisms in acute and bioconcentration tests. Because of the relative difficulty in maintaining saltwater aquariums, most testing is done on freshwater species.

## Exhibit 12-8

## RECOMMENDED TEST CONDITIONS FOR DAPHNIDS (*DAPHNIA PULEX*[a] AND *D. MAGNA*)

| | | |
|---|---|---|
| 1. | Temperature (°C) | 20 ± 2°C |
| 2. | Light quality | Ambient laboratory illumination |
| 3. | Light intensity | 50 to 100 footcandles (ft c)[b] (ambient laboratory levels) |
| 4. | Photoperiod | 8 to 16 hours light/24 hours |
| 5. | Size of test vessel | 100 ml beaker |
| 6. | Volume of test solution | 50 ml |
| 7. | Age of test animals | 1 to 24 hours (neonates) |
| 8. | No. of test animals per test vessel | 10 |
| 9. | No of replicate test vessels per concentration | 2 |
| 10. | Total no. organisms per concentration | 20 |
| 11. | Feeding regime | Feeding not required first 48 hours. For longer tests, feed every other day beginning on the third day (Appendix A). |
| 12. | Aeration | None, unless DO concentration falls below 40% of saturation, at which time start gentle, single-bubble aeration. |
| 13. | Dilution Water | Receiving water or other surface water, groundwater, or synthetic water: hard water for *Daphnia magna;* moderately hard or soft water for *D. pulex.* |
| 14. | Test duration | Screening test--24 hours (static tests)<br>Definitive test--48 hours (static tests) |
| 15. | Effect measured | Mortality--no movement of body or appendages on gentle prodding ($LC_{50}$) |

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[a] Use of D. pulex is preferred.

[b] ft c = foot candles

A 96-hour static toxicity test using the freshwater fish species fathead minnow, *Pimephales promelas*, is part of EPA's bioassessment protocol (Porcella, 1983). The following is a brief discussion of that test protocol. Details on test protocols using other species and flow-through systems are contained in Appendix 12B, which is the ASTM Standard Practice for Conducting Acute Toxicity Tests with Fishes, Macroinvertebrates, and Amphibians (ASTM Designation: E 729-80).

As with *Daphnia*, the fathead minnow was chosen because of its commonness, range of pH tolerance, temperature requirements, importance in the food web, and ready availability. Fish can be obtained from state, federal, or local hatcheries or from wild populatons in relatively unpolluted areas. Fish collected by electroshocking should not be used. The fathead minnows used in testing should weigh between 0.5 and 1.0 gram each, and the standard length (tip of snout to end of caudal peduncle) of the longest fish should be no more than twice that of the shortest fish. Weights and lengths are recorded before and after the test.

The same water-quality considerations discussed for *Daphnia* testing are true for fathead minnow testing. Test procedures are contained in Exhibit 12-9. The test results in the case of minnows is the concentration causing 50 percent lethality ($LC_{50}$) and is determined using any of the methods mentioned above for determining *Daphnia* test results. The 96-hour $LC_{50}$ are evaluated according to Exhibit 12-2.

#### 12.6.4.3.4 Aquatic Invertebrates

Laboratory tests and analyses using aquatic invertebrates include the classic acute toxicity tests and bioconcentration analyses. The most common acute toxicity test is a static toxicity test using *Daphnia*, a small freshwater crustaceans. Bioconcentration analyses are usually conducted on invertebrates consumed by humans, such as mollusks (e.g., mussels and oysters) and crustaceans (e.g., crabs and crayfish). The U.S. Mussel Watch program is an example of bioconcentration analyses using invertebrates to determine the degree of contamination occurring along the U.S. coasts (Goldberg et al., 1978).

#### 12.6.4.3.5 Bacteria

Bacteria can be used to assay a variety of potential impacts on biotic systems resulting from exposure to a contaminant or chemical compound. The following two types of bacteria assays can be used in study plans for hazardous waste sites.

##### Soil Respiration and Soil Litter Test

Soil micro-organisms are important recyclers of ecosystem nutrients. Their stress levels can be relatively easy to determine by measuring the carbon dioxide ($CO_2$) evolved from their respiration process. The results of this test show the percentage of inhibition ($EC_{50}$) or stimulation ($SC_{20}$) between $CO_2$ evolved in control and tested microcosms at specified time intervals.

This test used 1-quart (approximately 1 liter) wide-mouth jars with airtight lids and 1-ounce (30 ml) glass bottles with airtight lids. One hundred grams of air-dried artificial soil (Exhibit 12-6) in combination with test soil or soil extract (prepared as instructed in Exhibits 12-3 and 12-7) at specified concentrations are added to the cleaned wide-mouth jars. Deionized water is used to adjust the moisture content. A 1-ounce bottle containing $CO_2$ trapping solution is then added, and the whole test container is tightly sealed and placed in a dark, temperature controlled area (20 ± 2°C) for 14 days. Three special blank jars are used to correct for atmospheric $CO_2$ by placing a $CO_2$ trap in a clean, empty wide-mouth jar and running that jar at the same time as the test jars.

The $CO_2$ is typically measured twice weekly using the procedure for titrating $CO_2$ (Exhibit 12-10). Results are based on the total of all $CO_2$ measurements taken during the 14-day test. End results are either

## Exhibit 12-9
## SUMMARY OF TEST CONDITIONS
## (from Brusick and Young, 1982)

| | Fathead Minnow, *Pimephales promelas* |
|---|---|
| Temperature °C | 22 ± 1 |
| Photoperiod, hours light:dark | 16:8 |
| Water quality, hardness* mg/l as $CaCO_3$ | 100 |
| Container size | 20 liters |
| Test volume | 15 liters |
| Organism per container | 10 |
| Replicates | 2 |
| Feed | No |
| Duration, hours | 96 |
| Measurements of DO and pH, hours | 0, 24, 48, 72, 96 |

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*For dilution water only; the investigators add salts as appropriate to obtain 100 µg/l as CaCO3.

Source: Brusick and Young, 1982, as reported by Porcella, 1983.

an $EC_{50}$ (the lowest test concentration causing growth inhibition of 50 percent relative to control) or $SC_{20}$ (the lowest concentration causing growth stimulation of 20 percent relative to the control).

Microtox System

The Microtox system (from Beckman Instruments, Inc., Microbics Operations, Carlsbad, California 92008) measures the mean toxic response of approximately one million bioluminescent organisms to the introduced test medium. The system uses a Microtox analyzer to measure the light output of standardized marine bioluminescent bacteria that are grown and harvested by Beckman Instruments, Inc. The bacteria, called Microtox reagent, are lyophilized (freeze-dried under vacuum) and rehydrated by the user with a Microtox reconstitution solution.

Because of the standardization of all the variables described above, this test can yield results that can be compared from site to site. However, this method should be considered as a rapid screening tool that will lead to other bioassay tests. If the temperature is held constant at the "normal test temperature" of 15°C (analyzer range 10°C to 25°C), the primary variable in this system is time. Data results are the determination of the $EC_{50}$ or the effective concentration causing a 50 percent decrease in the Microtox reagent light output under specified time (*t*) and temperture (*T*). To compare information, the user must know time and temperature data.

The length of time it takes for the reagent to react varies greatly with the test medium. However, the normal reaction will occur after between 5 to 15 minutes have elapsed. Readings at 5 and 15 minutes are recommended, with additional readings if it appears that more time is needed. For example, phenols are a class of toxicants that cause immediate light loss followed by either a slight recovery or a stable light output, whereas bivalent metals exhibit slow inhibition reactions and may require longer test times.

The reader should obtain the Microtox manual from Beckman Instruments, Inc., for detailed test procedures.

Because this test is conducted with a single species, the results are primarily indications of relative toxicities of sites and are not indications of the actual toxicity of the hazardous material.

## 12.7 REGION-SPECIFIC VARIANCES

Regional variances exist. Climatic differences will influence different responses with standardized test organisms. Regional differences also exist in native plants and animals that are on hazardous waste sites. The reader is urged to contact the appropriate EPA RPM for referral to the knowledgeable technical specialists. Regional variances will be updated in Revision 01 to this compendium.

## Exhibit 12-10
## PROCEDURES OF TITRATING $CO_2$ IN TRAPS AND METHODS FOR PREPARING REAGENTS

### A. $CO_2$ TITRATION PROCEDURE

1. Replace the $CO_2$ traps at the designated intervals by opening the microcosm, removing the exposed $CO_2$ trap, and replacing it with an unexposed one. (At the same time this step is being performed, insert an open vacuum line to aid in properly replenishing the air in the microcosm. Remove at least 3 times the volume of the air space.)

2. As quickly as is practical, place an airtight cap on the exposed $CO_2$ trap; return the microcosms to the dark 20°C incubator.

3. Add 5 ml of 1.3N of $BaCl_2$ and a stir bar to each exposed $CO_2$ trap immediately before titration.

4. Titrate excess 0.6N NaOH remaining in the trap to pH 9.0 with a buret and pH meter (or autotitrator) using Trizma standardized 0.6N HCl to measure milligrams of $CO_2$ produced.

### Formula for the Calculation of $CO_2$ Production

mg of $CO_2$ = (Blank ml - Sample ml) x 22 mg of $CO_2$/ml/N x Normality of Acid
e.g., mg of $CO_2$ = (10.40 ml - 6.93 ml) x 22 mg of $CO_2$/ml/n x 0.6013 N
= 45.90 mg of $CO_2$ produced

### B. PREPARATION OF REAGENTS

1. 0.6N NaOH
   - a. Rinse 20-liter glass carboy with distilled $H_2O$.
   - b. Place on a large magnetic stir plate; add degassed distilled $H_2O$ to the 18.9 liter mark.
   - c. Add 454 grams (1 lb) of NaOH pellets.
   - d. Stopper and stir overnight before use. (Maintain the NaOH stock solution in a $CO_2$-free atmosphere by using ascarite traps.)

2. 0,6N HCl
   - a. Rinse 20-liter glass carboy with distilled $H_2O$.
   - b. Add 1.0 liter of concentrated HCl.
   - c. Add distilled $H_2O$ until the 20-liter mark.
   - d. Stopper and stir overnight.

**Exhibit 12-10**
**(continued)**

e. Titrate 5 "Tris" samples (0.5 to 0.9 grams of "tris" in 10.0 ml of distilled $H_2O$ and 5 ml of 1.2 $BaCl_2$) to pH 5.0 with about 0.7 HCl; calculate mean and standard deviation ("s"). (If "s" is larger than 0.0015, do 5 more samples and combine results.)

$$\text{Normality of HCl} = \frac{(0.1211\ \text{g/meq})\ (\text{ml of HCl used})}{(\text{Weight of Tris in grams})}$$

$$= \frac{(0.1211\ \text{g/meq})\ (9.69\ \text{ml})}{0.7089\ \text{grams}}$$

e.g., Normality of HCl = 0.6041N

3. 1.3N $BaCl_2$
   a. Weigh 317.56 grams $BaCl_2{:}2H_2O$
   b. Dissolve in degassed distilled $H_2O$ in a 1-liter volumetric flask.

4. Tris
   Aminomethane (hydroxymethyl) tris--Trizma Base (Sigma Chemical Company, St. Louis, Missouri).

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Source: Lighthart, 1980; unpublished procedure as reported by Porcella, 1983.

## 12.8 INFORMATION SOURCES

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# APPENDIX 12A

# COLLECTION AND PROCESSING TECHNIQUES

## A. VEGETATION COLLECTION TECHNIQUES

Two general types of information can be used to determine the level of impact of any pollutant on vegetation. First, the general health and stress level of plants on the site should be assessed. This can be done with superficial visual observations, through remote sensing using color infrared photography, and by tissue analysis. Second, the composition of the plant community can be measured through an ecological survey to determine if the stress has been great enough to change the relative abundance of the vegetation.

Assessing the stress level of the plants growing on a site is appropriate for determining subtle environmental effects. By the time an impact is severe enough to change the species composition of a site, it may be pointless to review existing vegetation for stress effects.

Important factors to consider in analyzing the effects of pollutants on the terrestrial ecosystem include how the pollutant entered the ecosystem (for example, by a spill on the soil surface, or through contamination of an underground water table); the time of entry of the pollutant in relation to the season of the year and the life-cycle of principal life forms; the physical and chemical nature of the soil, especially infiltration rates, internal drainage, buffering capacity, and soil pH; the nature of the vegetation, especially plant rooting depths, litter quantity, and rate of organic matter turnover; specific types of potential human and animal food produced by the vegetation, such as crops, deer browse, edible nuts; and animal use of the area, including identification of resident and migratory species.

### A1. Visual Field Observations

During site surveys, an ecologist should observe the vegetation throughout the vicinity and in downgradient (downwind, downstream, and downhill) areas. It may be desirable to make such observations at different times of the year, especially during the spring growth of the major species, during a period of high heat-and-water stress in the summer, and just before leaf fall in the autumn. These are times when symptoms of stress may be particularly obvious, especially if there is a chance that the pollutant has impaired the function of the root system.

Team personnel should determine the types of vegetation expected to be found and the successional stages common to the area. It is imperative that the length of time since site disturbance or site abandonment be known to interpret properly these visual assessments. Signs of stress that need to be assessed in both the affected and unaffected areas include size of annual or biennial plants, leaf size of perennial plants, leaf and stem necrosis, chlorosis, evidence of changes in levels of disease or insect damage that may be linked to stressed plants, increases in size of seed crops of perennial plants (often associated with stress), premature leaf fall, abnormal wilting of succulent plant parts, and abnormal plant coloration.

### A2. Remote Sensing

When the site vicinity is large or the possible offsite pollutant pathways are extensive or unknown, aerial photography using color infrared (CIR) film can be used to identify and delineate the extent of vegetational stress. Field checks are necessary to substantiate conclusions made by the examination of CIR photographs. The success of this method depends on the experience and interpretive abilities of the investigator and on the amount of information available about the expected effects of the pollutants on vegetation.

Remote sensing may be applicable only at certain times of the year and is probably most effective during the warmer, drier periods of the growing season. Additional information can be found in the following:

- Reeves, Robert G., Abraham Anson, and David Landen. *Manual of Remote Sensing*. Falls Church, Virginia: American Society of Photogrammetry. 1975.
- Schemnitz, Sanford D., ed. *Wildlife Management Techniques Manual*. Washington, D.C.: The Wildlife Society. 1980.

## A3. Ecological Assessments

There are a number of ecological survey techniques available for obtaining quantitative, defensible information about the structure, composition, biomass, and productivity of plant communities. Ecological surveys conducted simultaneously in a (possibly) affected area and a reference area can demonstrate vegetational stress if exposure to site contaminants is the only difference between these two sites. The most common survey techniques include plot sampling, plotless sampling, and line-intercept sampling.

Plot sampling is frequently used to quantify species composition within an area. For this purpose, plots are laid out in the study area on either a random or systematic sampling basis. Plot sizes vary with the size of the vegetation being sampled. (If the composition of a stand of large plants, such as trees or tall shrubs, is being quantified, the plots may be, for instance, 10 m x 10 m; however, if the composition of a stand of annuals is being measured, plot size may be only 1 m x 1 m.) The size and number of plots sampled is also a function of the uniformity of the plant community. In plant communities with multiple layers—for example, in a temperate forest with an over-story canopy, a shrub layer, and a herbaceous layer—three different plot sizes may be used, each of the smaller plots being a subsample of the next largest plot.

Once the plots are laid out, the scientist estimates the percentage of the plot covered by a projection of the leaves of each species onto the ground. By taking several of these plots within a study area, an average percent-cover is calculated for each plant species.

In a variation of this plot-sampling technique, the scientist harvests all plants growing within a plot, sorts them by species, and weighs them. This technique gives a more precise measure of species composition, but it is more costly. Data gathered from harvested plots can be compared to data gathered from "percent-cover" plots only with a great deal of care.

Plotless sampling is an alternative to the establishment of plots when the plants to be sampled are widely spaced, as in arid or otherwise semi-barren areas. There are several plotless sampling procedures. One common procedure involves the selection of random points in a plant community. At each point, four quadrants of 90 degrees each are established. In each quadrant, the distance from the point to the nearest plant is measured. The nearest plants can be measured for whatever parameters are of interest, including the projected area of the leaves of the plant upon the ground. The point-to-plant distance squared is, on the average, the mean area occupied by one plant. The percentage of coverage by species can be calculated from this data. Again, the number of sample points required depends on the accuracy required in the study and the uniformity and distribution of plants within the community.

The line-intercept sampling method is particularly useful in quantifying low-growing vegetation. In this technique, a randomly oriented line is laid out on the ground. The scientist then moves along the line, measuring and recording the length of the line under the projected leaf area of each plant. The length of line covered by each species is divided by the total length of the line to determine a percent-cover for each species. By laying out a number of short lines, or by arbitrarily dividing a long line into segments, species frequency can be determined.

Each of the sampling techniques presented here can be used to gather a variety of information. The examples above primarily illustrate the mechanics of each technique.

Quantitative ecological vegetation assessments are rarely done in hazardous waste site studies because they are labor intensive and because little additional information is gained for use in a human health risk assessment beyond that information available from the visual site investigation. For these reasons, vegetation sampling techniques should be selected on a site-specific basis. Several references are available for use in designing quantitative vegetation study plans, including the following:

Cox, G.W. *The Laboratory Manual of General Ecology*. Dubuque, Iowa: Wm. C. Brown Co. 1967.

Phillips, E.A. *Methods of Vegetation Study*. New York: Holt, Rinehart and Winston. 1959.

Brown and Zan. *Field and Laboratory Methods for General Ecology*. 1977.

## A4. Tissue Analyses

Plant tissues can become contaminated by metals, organics, and various other elements of environmental concern. The type of plant and/ or plant tissue collected for analysis will depend on site conditions. Approximately 30 grams (wet) of plant tissue are normally needed for analysis, but the number and type of analyses required will determine how much material must be collected. The laboratory performing the analysis will inform the collector of the amount of material needed and any special handling methods required. Grasses and forbs should be clipped just above ground level using scissors or plant shears. No soil should be included in the material collected. Samples should be placed in clean 1-gallon paper bags as described in Subsection E1 of this appendix.

Leaves collected for analysis should be clipped at the petiole and allowed to drop directly into the collecting bag. All flowers, leaves, and other plant growth should be removed from plant stems collected. Stems are then cut into 3- to 4-inch lengths and allowed to drop directly into the collecting bag.

All leaf, flower, or cover tissue is removed, if possible, from fruits, nuts, or seeds. If this is not possible in the field, the sample label should indicate what part of the sample is to be analyzed.

Roots, tubers, or other underground plant growth are handled differently than above-ground plant tissue. Underground structures are collected by digging with a trowel or other tool, rather than by pulling the plant out of the ground. The entire root system is carefully collected, and attached soil is gently removed by shaking or striking. (Some soil will remain, but the laboratory will clean the material prior to analysis.) The root should be cut away from the stem at ground level, and each root placed in a separate bag and labeled as described in Subsection E1 of this appendix.

## B. TERRESTRIAL VERTEBRATE FIELD COLLECTION TECHNIQUES

Assessments of effects on terrestrial vertebrates can be accomplished through tissue analysis and through ecological survey techniques. Collection techniques for tissue analyses of terrestrial vertebrates normally involve small to medium-sized animals. The most common techniques are live trapping, lethal trapping, and hunting with a gun. Other assessments used on terrestrial vertebrates include mark and recapture studies and scatological studies. The U.S. Fish and Wildlife's Habitat Evaluation Procedure (HEP) incorporates vegetation and wildlife survey techniques to estimate natural resource losses expected over time as a result of a specific project. The reader should also refer to Subsection B4 – Habitat Evaluation Procedure of this appendix.

The collection of terrestrial vertebrates at any site can serve a multitude of functions, including identification of species present, estimation of total numbers of each species, and securing of tissue for chemical analysis. Because of the time and expense involved, the collection procedures are usually used only when tissue residue studies are needed.

### B1. Live Trapping

Live traps completely enclose the captured animal. This system normally does not kill the captive; however, some animals may become hurt in their attempts to gain freedom or may die from exposure if the traps are not properly insulated. Death because of exposure occurs most frequently during cold or rainy weather. Live traps should be checked frequently.

Live traps can be used in ecological surveys or, more typically, for capturing specimens for tissue analysis. Live traps allow the collector to be selective because unwanted species can be released unharmed.

The most commonly used live traps are small, medium, or large Havahart traps or Peterson live traps (Exhibit 12A-1). Havahart traps are used for squirrel-sized or larger mammals, while Peterson traps (with dimensions of 3 x 3 x 9 inches) are used for small, rodent-sized animals. Traps can be baited with a variety of food such as smoked fish, oatmeal and peanut butter, birdseed and peanut butter, or other appropriate attractants.

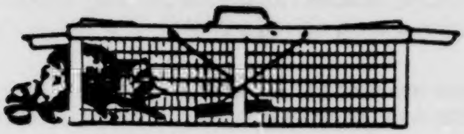
Before it is used for the first time, a trap is specially cleaned with a trap dye to remove the scent accrued during manufacture; it is then treated with sealing wax to reduce rusting. Gloves are used to handle the trap so that human scent is not associated with it.

Trap placement is determined by the species to be captured. Carnivores, omnivores, or herbivores with relatively small home ranges (less than 20 acres) are considered to be the most likely terrestrial vertebrates to have come in contact with site contaminants. Mammals such as opossums, rabbits, woodchucks, mice, moles, shrews, muskrats, and raccoons are the most commonly collected mammals.

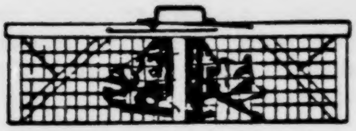
The site vicinity is examined by biologists to identify likely habitats and animal trails. Live traps are baited, wired open, and placed in likely areas for 2 to 3 days to acquaint animals with the foreign object. Following the acquaintance period, the trap is baited and set to close when tripped.

The number of animals needed for tissue analysis depends on the species available, the target tissue (e.g., muscle, liver, brain), the number and types of analyses to be done, and the detection limit required for study objectives. The primary laboratory protocol used (see EPA, 1980c in Subsection 12.8) requires a minimum of 10 grams for base/ neutrals and acids, 10 grams for pesticides and PCBs, 5 grams for volatiles,

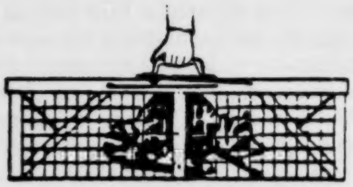
## Exhibit 12A-1
## LIVE ANIMAL TRAPS



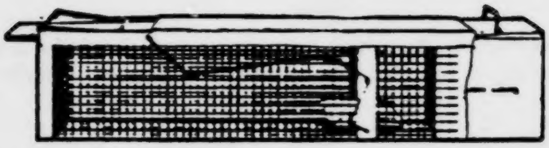
1 **ANIMAL ENTERS.** Lured by bait on bait pan or fooled by trap set on runway, animal enters trap. Animal can see through open ends of trap and enters unsuspectingly.



2 **DOORS SLAM AND LOCK.** Animal trips bait pan and doors slam shut. Door design restricts animal movement to help prevent injury.



3 **READY TO GO.** Pets and non-target wildlife can be released immediately Pests can be transported in trap for relocation and release Trap doubles as a handy animal carrier.



**For Foxes, Raccoons, Bobcats, Otters**
Special single-door trap with compartment for live chicken, rabbit or other bait. Size 55" x 12" x 12".

and 10 grams for metals. Approximately 100 grams of the target tissue is usually required. Trapping an adequate number of a single species may sometimes be difficult within the schedule of the sampling program.

Field notebooks (bound, with numbered pages) are kept to record all field data, including sampling locations, date, weather conditions, species caught, weight, length, sex, and any unusual biotic condition observed. Photographs including a scale object, are made of all specimens retained for sacrifice.

Animals to be used in tissue analyses can be killed with a shot to the head, by suffocation, or by breaking the neck. The animal is dissected according to the procedure described by Henry S. Mosby in *Manual of Game Investigational Techniques* (U.S. Wildlife Society, 1960). Another important reference in wildlife collection is the *1980 Wildlife Management Techniques Manual* (The Wildlife Society, S.D. Schemnitz, ed.). (See Subsection 12.8 for information source.) Additional details on tissues sampled and sample preservation are provided in Subsection E2 of this appendix.

The "mark-and-recapture" system of live trapping is useful for estimating population sizes. In this system, a number of animals of a particular species are trapped alive, marked in some way, and returned to the ecosystem. After allowing a brief interval for the marked animals to meld into the population, a large number of traps are set and animals are captured. The population of animals in the ecosystem can be calculated based on the number of animals marked, the number of marked animals recaptured, and the total number of animals captured in the second trapping. Information on the size of animal populations might reveal whether or not the environment has been seriously disturbed by some factor, such as a pollutant, but this technique is not likely to be useful when the polluted area is very small.

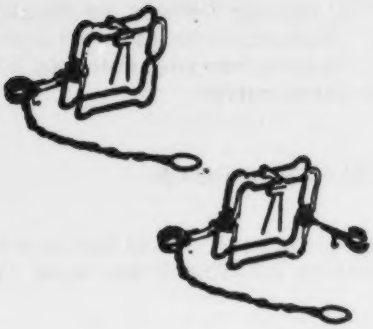
## B2. Lethal Traps

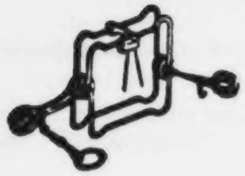
Lethal traps physically grab and retain animals once the trap is tripped. This type of trap is used to collect such animals as muskrats, raccoons, minks, or skunks (which are more easily handled by this method) for tissue analysis. Common traps used include the Victor No. 1 coil spring leg trap, the Conibear No. 1 body trap, and the museum special, Victor rat traps (Exhibit 12A-2). Traps are baited and/or set along identified animal trails, preferably at night. As with live traps, lethal traps are specially cleaned and prepared to reduce human scents and improve the catch.

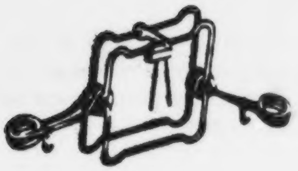
The ambient temperature helps to determine how often a trap should be checked, because heat and low humidity can decay or dessicate samples. The following frequency is recommended:

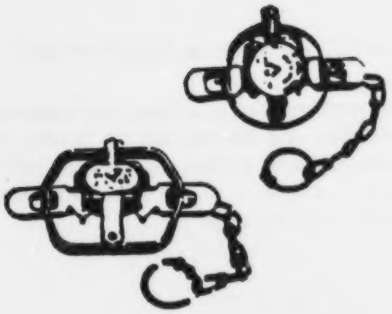
- Below 50°F at night, traps can be left out overnight.
- Below 50°F during day, traps should be checked every 4 hours.
- Between 50°F and 80°F at night, traps should be checked every 4 hours.
- Between 50°F and 80°F during day, traps should be checked every 2 hours, especially on sunny days.
- Above 80°F at night, traps should be checked every 2 hours.
- Traps should not be set during daylight hours if the temperature is above 80°F unless traps are continuously checked.

## Exhibit 12A-2
## LETHAL ANIMAL TRAPS









Captured organisms are killed and processed in the same manner as described in the live trap subsection above.

## B3. Hunting

Species not easily captured by trapping methods are occasionally obtained by standard hunting methods using a .22-caliber gun. Large aquatic turtles are an example of such a species. Once the organism is killed, it is processed in the same manner as described in the live trap subsection above. Hunting is used to collect organisms for tissue analysis.

## B4. Additional Ecological Assessments

Ecological assessments of hazardous waste sites to date have been very limited. Terrestrial, aquatic, and marine ecological studies may be called for in the future. The following references will provide guidance:

Brown and Zan. *Field and Laboratory Methods for General Ecology*. 1977.

Cox, George, W. *Laboratory Manual of General Ecology*. Dubuque, Iowa.: William C. Brown Co. 1967.

Updates of this compendium will incorporate any ecological techniques applied through the date of preparation. The Habitat Evaluation Procedure (HEP) discussed below is a tool that can be applied to hazardous waste site evaluations.

### Habitat Evaluation Procedure (HEP)

The U.S. Fish and Wildlife Services (FWS) HEP is part of the methodology being assessed by the Department of Interior for use in establishing a monetary value for natural resources lost because of hazardous waste sites. This procedure might be used in rural settings where wildlife resources have been lost, but it would have limited use in urban areas.

There are two possible objectives to this type of study. The first is to evaluate the impacts of the site on wildlife, using the HEP methodology. The second is to develop a conceptual mitigation plan describing the possible replacement of wildlife habitat or other mitigation to compensate for the habitat affected by the site. Following is a brief summary of the major tasks involved in conducting the HEP.

Task 1. Literature Review and HEP Evaluation Team Formation

Wildlife biologists meet with personnel from federal and state resource agencies and other appropriate agencies to gather existing published and file data and to identify significant issues or resources related to the site vicinity. Representatives of these entities will form an HEP evaluation team. This team identifies species of interest, clarifies agency concerns, and provides an opportunity for agency input into the design phase of the study. This task also includes a site visit.

## Task 2. Study Definition

The results of Task 1 activities are used to determine several elements of the study. The study area is roughly defined, and an initial selection of evaluation species is made. The inclusion of species is determined jointly by representatives of the HEP evaluation team.

Selection of evaluation species is determined by several criteria and may include species of special concern, such as threatened or endangered species, or species of interest to the wildlife resource agencies because of their management significance as game species. Additionally, the list of evaluation species may include representatives of several guilds (that is, species with similar nesting or foraging requirements), to provide an ecologically balanced approach to the study. A maximum of eight evaluation species are usually selected. If possible, the study should select only species for which published verified models or habitat suitability index (HSI) curves are available.

An evaluation team meeting is then held to discuss species selection, modify species models as necessary, and clearly establish study goals and objectives.

## Task 3. Habitat Inventory and Study Site Selection

Aerial photographs taken from before site development to the present are obtained for the study area. These photos, combined with onsite visual verification and any other available data sources (such as timber harvest records, land use maps, or old zoning records) are used to classify the cover types in the area under existing and baseline conditions. Photos are also helpful in determining succession and agricultural or silvicultural practices on lands adjacent to the site.

In evaluating an existing site using the HEP methodology, it is necessary to identify cover types in the study area that can be used to represent uncontaminated baseline conditions. An underlying assumption is that these baseline areas represent conditions at the site before contamination. This assumption is critical because baseline conditions establish the standard against which impacts are measured.

The results of the habitat inventory can be presented in several ways. Each cover type can be described using standard FWS habitat classifications (where appropriate), and can include a description of the dominant species in the tree, shrub, and ground layers as well as estimates of canopy coverage, tree height, and diameter breastheight (d.b.h.), as appropriate. Specific methodologies that can be used are described in *Laboratory Manual of General Ecology.* (See Subsection 12.8 for Cox, G.W. Dubuque, Iowa: Wm. C. Brown Co. 1967.)

A copy of the draft report of the habitat inventory results is to be sent to each HEP evaluation team member along with HEP models for the evaluation species. The evaluation team then meets to select specific sampling locations, develop the sampling design, and make any final modifications to the evaluation species models.

Sampling sites are selected in each of the major plant communities and successional stages, as represented by the cover types described in the habitat inventory. Sampling sites are selected by a stratified, random process whereby the number of sampling sites per cover type will be approximately proportional to the total area and to the amount of variability within each type. Where possible, an equal number of sample sites are selected and evaluated in each of the three major areas of study: baseline, impact, and mitigation sites.

### Task 4. Conduct, Analyze, and Interpret HEP Assessment

Following the selection of study sites and evaluation species and the finalization of the study design, the actual field methodology used to collect data is fairly straight forward. Each study site is sampled by the evaluation team in accordance with the HEP guidelines. Target years for analysis usually include a year before the contamination (a year that has aerial photos available), a year close to the present (again determined by the availability of aerial photos), and a year 1 or 2 years in the future, usually after remediation.

In the HEP methodology, each species model uses a number of measurable variables that are combined into a simple equation, resulting in a sample site HSI. The average HSI from all sample sites is used as the HSI value for a given evaluation species in the study area. This overall HSI, which is a number between 0 and 1.0, is a quality index or a measure of the capacity of the project area to meet the life requisites of the evaluation species.

The overall HSI, when multiplied by the number of habitat acres for the evaluation species, yields the number of habitat units (HUs), a measure of the quality and quantity of habitat available to the evaluation species. The difference in HUs for each evaluation species between the target years represents the losses or gains of the habitat in terms of quantity and quality as a result of the project or mitigation measures.

## C. AQUATIC MACROINVERTEBRATE FIELD COLLECTION TECHNIQUES

Collection techniques for freshwater and marine macroinvertebrates are discussed below. These techniques include quantitative and qualitative methodologies focused on benthic infauna or epifauna and can be used to collect specimens for tissue analysis or ecological surveys. All of the methods that identify collection of invertebrates from sediment require the use of personal protective gear appropriate for the level of contamination expected.

### C1. Grabs / Coring Devices / Sediment Sampling Methods

Aquatic invertebrates inhabiting soft substrate can be sampled by collecting the substrate and selving it through one or more standard screens to extract organisms. Sampling methods include bottom grabs, sediment coring devices, and shovels. The screening extraction method is described in Subsection C2 of this appendix.

Invertebrates collected by sediment sampling devices live on or in sediments where many pollutants can accumulate. For this reason, these organisms are often good indicators of the effects of contamination. Invertebrates can be used in tissue analysis studies or ecological assessments. Bivalves and larger crustaceans are normally used in tissue analyses, while the invertebrate population as a whole can be studied in ecological surveys.

Marine and freshwater invertebrates are collected primarily by grabs such as the Ekman, Ponar, Smith-McIntyre, or Petersen. Intertidal or shallow-water sediment-dwelling invertebrates are commonly collected with a Surber sampler (or other standard gear) or with a shovel. Sediment coring devices, while impractical for collecting organisms for tissue analysis or ecological surveys because of their small sample area, can be useful in obtaining a relatively undisturbed sediment sample for analysis of pollutant accumulation over time.

The various sediment grabs operate by digging into the bottom using their weight and leverage. Shallow waters can be sampled with some of these grabs by rigging them on poles or rods and pushing them into the substrate. Grabs can sample substrate ranging from soft muds through gravel. The Ekman grab is most useful in sampling soft sediments; for clay hardpan and coarse substrates, the heavier grabs such as the orange peel or clam shell type (including the Ponar, Petersen, Shipek, and Smith-McIntyre) are better. Exhibit 12A-3 shows various grab samplers.

Medium-sized boats equipped with winches are normally necessary to deploy and retrieve grab samplers. The substrate collected is funneled into either a box screen or a bucket to await screening. *Standard Methods for the Examination of Water and Wastewater*, 16th ed. (APHA AWWA-WPCF, 1984), contains detailed descriptions of the most popular grab samplers.

Core samplers vary from hand-push types to gravity-operated types. The length of core taken by gravity or by hand will vary with substrate texture and density and the amount of weight or effort expended.

Grabs and corers are operated according to manufacturers' specifications. If the study plan calls for ecological data, invertebrates are collected according to the methodologies described in EPA's *Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents* (Weber, 1973) or in *Standard Methods for the Examination of Water and Wastewater*, 16th ed. (APHA-AWWA-WPCF, 1984). In both tissue analysis and ecological survey studies, samples are collected from both the test or affected area(s) and a reference site. Ecological surveys require replicate sampling, while tissue analysis sampling requires approximately 100 grams of tissue of a single species. As discussed in Subsection B1 of this appendix, the amount of tissue needed can vary.

Sampled organisms are handled and preserved in the field according to the procedures described in Subsection E3 of this appendix.

## C2. Sieving Devices

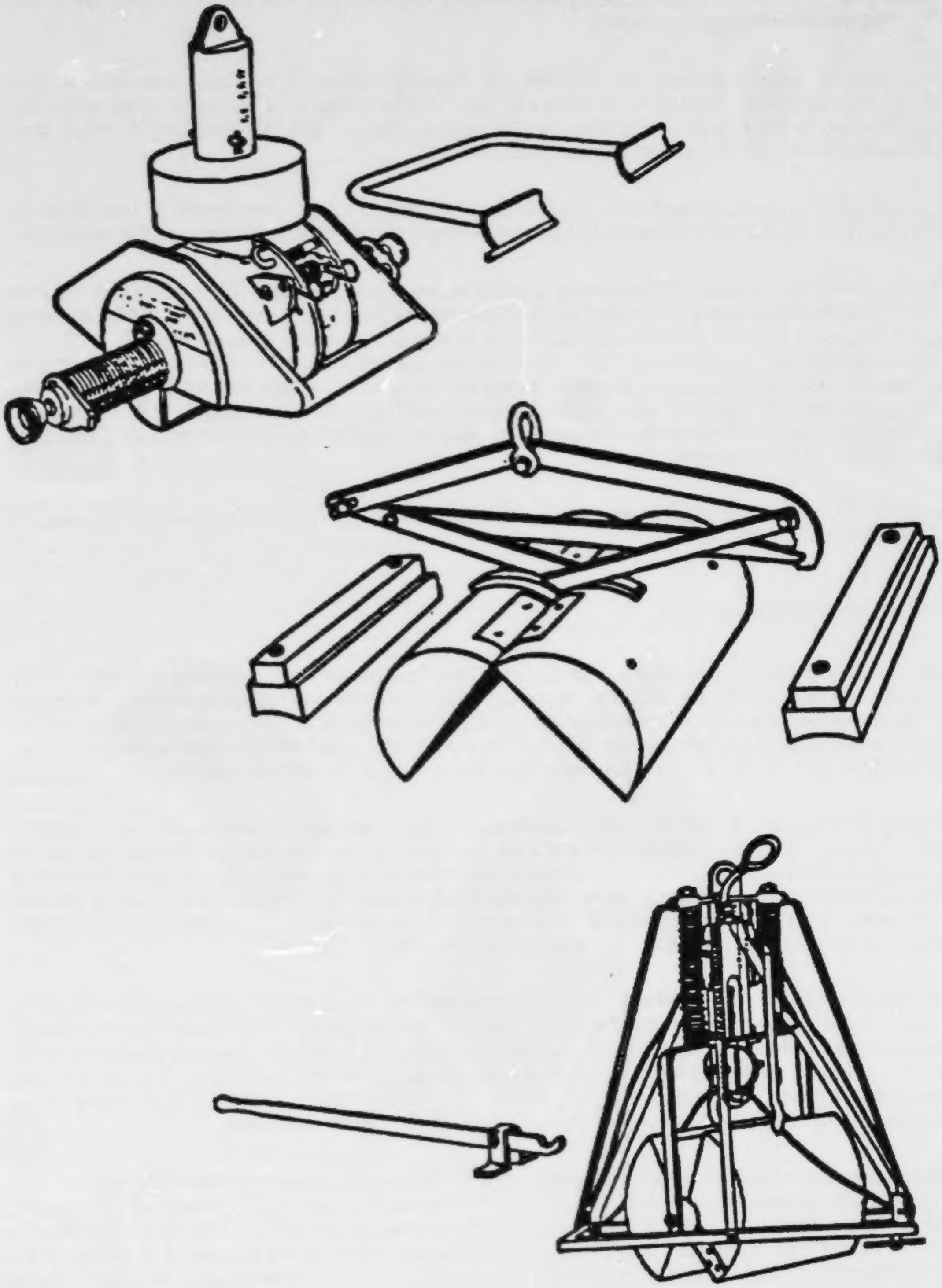
Sieving devices remove aquatic invertebrates from their habitats, either by capturing organisms larger than the sediments in which they live or by capturing organisms drifting in the water column. In the first case, box-type sieves are used in conjunction with grab-collection methods (Subsection C1 of this appendix). In the second case, invertebrates are sampled from rubble and gravel riffles in streams using a Surber-type sieving device (Exhibit 12A-4) or from the water column using an invertebrate drift net.

Sieving devices can be used to collect specimens for tissue analysis. These devices are especially useful in collecting sediment-dwelling mollusks, both freshwater and marine species. Sieves can also be used in ecological survey studies when a quantitative sediment sampling method is employed (Subsection C of this appendix). Surber samplers can be used with relative ease as sampling devices for small streams and are useful for comparative types of ecological studies (i.e., upstream versus downstream). Surber samplers can be used only in flowing water with a depth of less than 12 inches.

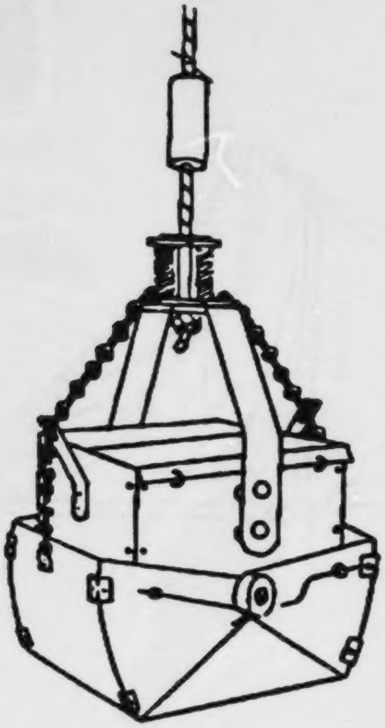
Surber samplers are composed of a stainless steel square frame and attached nylon net, typically 0.21-mm mesh. The sampler is placed over the sample site, and all sediments within the frame are disturbed to loosen attached invertebrates. Larger rocks are lifted, scrubbed, and removed. Remaining sediment is disturbed to a standard depth (usually 2 to 4 inches) by digging and stirring either by hand or using a tool. Net contents are rinsed into the bottom of the net with local water and then carefully removed to the collection container. Stainless steel forceps are often useful in removing small specimens.

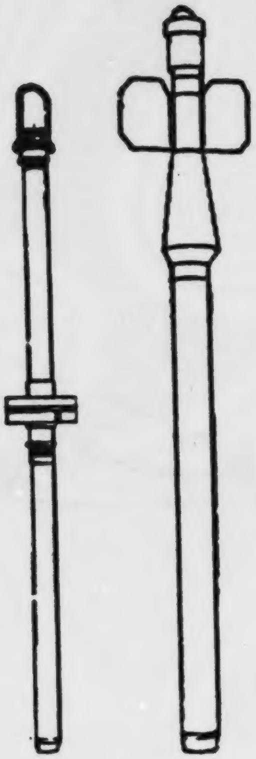
Benthos screens used to process grab-type samples are usually about one-half-meter-square, low-sided boxes with bottoms made of 0.25-inch or finer stainless steel or nylon mesh. Sediment samples are placed in the box, and local water is used to wash sediment through the mesh. The washing process is usually performed from the bottom upward so as not to mutilate more delicate organisms of interest. Collected specimens are then removed to collection jars or aluminum foil, depending on the type of study

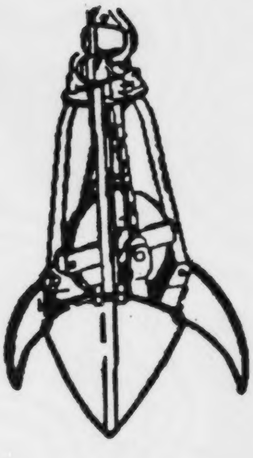
## Exhibit 12A-3
## TYPES OF GRAB SAMPLERS

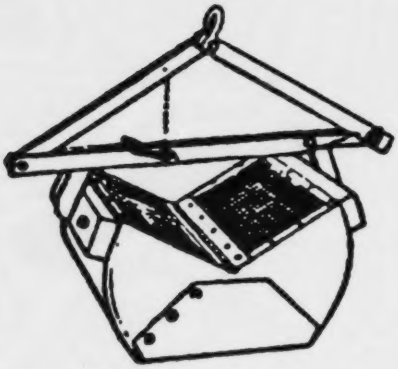


## Exhibit 12A-3
## (continued)

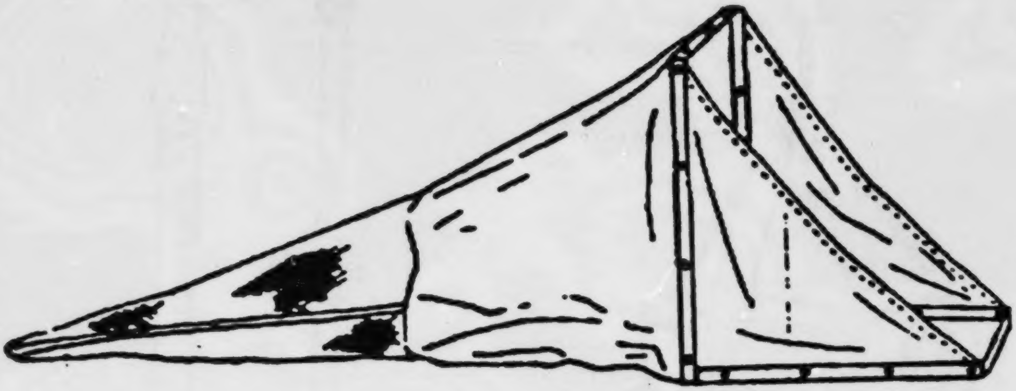








# Exhibit 12A-4
# SURBER SAMPLER



being conducted. Sample handling techniques and preservation are discussed in Subsection E3 of this appendix.

Invertebrate drift nets are small, funnel-shaped, fine-meshed nets with a rectangular opening and a typical bag length of 1.3 meters. These nets are anchored in small, swift streams (minimum current of 0.5 feet per second) above the bottom and slightly below the surface. This type of net is useful for collecting macroinvertebrates that migrate or are dislodged from the substrate.

This sampling methodology can be used to collect organisms for tissue analysis or for ecological surveys. Important factors in obtaining quantitative ecological data are net opening size, duration of operations, stream flow, time of day, and season.

Examination trays, either stainless steel or white enamel, are often used in the field to do the initial sorting of collected invertebrates. Sample handling techniques and preservation are discussed in detail in Subsection E3 of this appendix.

## C3. Otter Trawl

Marine macroinvertebrates associated with the surface sediment are collected in otter trawls along with demersal fish. This sampling method is described in Subsection D1 of this appendix.

Invertebrates collected by this method are handled and preserved by the techniques described in Subsection E3 of this appendix.

## C4. Traps

Minnow or crab traps are screened devices that are baited with an attractant to lure species of interest. These traps are most commonly used to collect organisms such as crayfish or marine crabs to be used in tissue analysis.

Traps are baited with items that will attract the species of interest. Crayfish, for example, are scavengers and will be attracted to any odorous food item such as fish or cat food. The traps are then set on or near the site and at a reference site and are checked at appropriate time intervals. Specific trapping methodologies will vary with the organism of interest. Once the organisms are collected (at least 100 grams per sample), they are handled as described in Subsection E3 of this appendix.

## C5. Artificial Substrate

Artificial substrate samplers are devices that are placed in the water for an extended period for colonization by macroinvertebrates. This sampling technique can be used to collect invertebrates (such as small crustaceans, insects, and other arthropods) for tissue analysis. These devices can be used in ecological studies if a standard artificial substrate sampler is used at both the reference and study locations and if care is given to placing the substrates in equal water depth and under equal conditions for equal time periods.

Because artificial substrate sampling methods can take extended amounts of time (4 to 6 weeks), other available methods may be preferable. However, in monitoring studies, artificial substrates can provide information concerning relative environmental conditions. This is one of the only means for obtaining quantitative data relative to benthic colonization in areas where substrate conditions may not allow invertebrate colonization or where organisms are scarce, making other collection efforts difficult.

The most common standard samplers are the multiplate or Hester-Dendy sampler and the basket sampler (Exhibit 12A-5). The multiplate sampler is positioned (preferably) in the top meter of water, using floats and stainless steel cable, for 4 to 6 weeks. For maximum retention of organisms during retrieval, the sampler is placed in a bag or large dip net while still positioned in the water.

A basket sampler is a cylindrical basket containing approximately 30 rocks of equal size. This device is often used in creeks and rivers where rocks are the preferred habitat for most invertebrates. Such samplers are also left in place for 4 to 6 weeks.

Organisms removed from either artificial substrate are processed using techniques described in Subsection E3.

## C6. In Situ Bioassays

During this procedure, local invertebrates from a comparatively clean area or invertebrates raised in laboratories under known conditions are confined in traps and held at the site and at a reference site to determine the acute toxicity of the area of suspected contaminants or to determine whether bioaccumulation is occurring.

Approximately 40 to 50 organisms such as bivalves or crayfish are obtained. Then 10 to 15 organisms are placed in two cages—one for the test area and one for the reference area. If the purpose of the study is to determine bioaccumulation, 10 to 15 additional specimens are sacrificed and processed immediately to establish baseline conditions. The test and reference cages are checked on a regular schedule to determine mortalities. If bioaccumulation is being studied, several specimens are sacrificed at set time intervals over the study period. Specimens for analysis are handled and preserved as described in Subsection E3 of this appendix.

## C7. Miscellaneous Invertebrate Collection Techniques

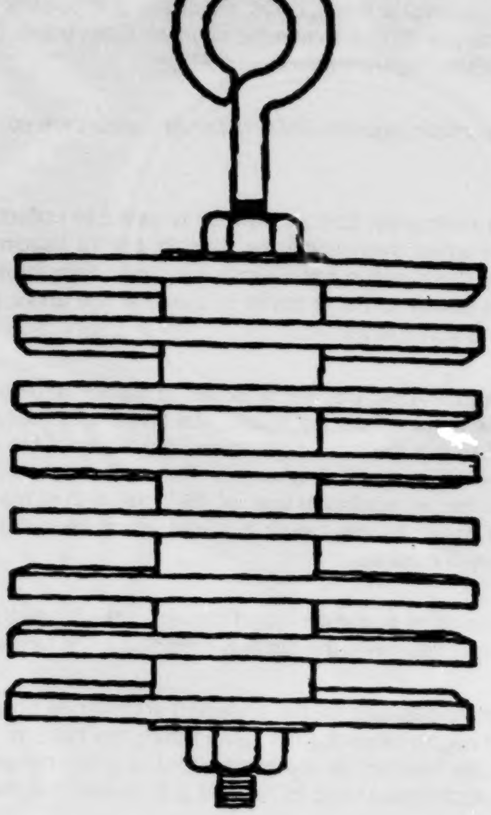
Aquatic invertebrates can be collected in a variety of other ways, depending on the species and habitats being sampled.

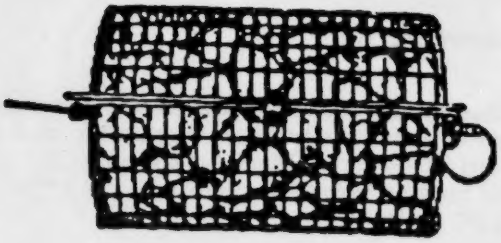
Other sampling devices that can be used include garden rakes, pocket knives, buckets, tongs, dip nets, and hands. Any of these methods would best be used for collection of organisms for tissue analysis and not for ecological surveys since they are difficult to quantify.

## D. FISH FIELD COLLECTION TECHNIQUES

Collection techniques for gathering biotic information on both freshwater and marine fish species include trawling, seining, hook and line, and in situ bioassays. Electroshocking is used in freshwater systems only.

## Exhibit 12A-5
## SUBSTRATE SAMPLERS





## D1. Trawls

The trawl method of sampling fish consists of dragging an open net through a body of water with a boat. The net is set at the appropriate operating depth to catch the species of interest. This sampling method is used in large, open-water areas of reservoirs, lakes, rivers, estuaries, and oceans. Irregular bottoms or areas with snags or large debris items are difficult to sample by trawl. Otter trawls (Exhibit 12A-6) are commonly used because they can be operated from a relatively small boat.

The otter trawl method is used to sample bottom species while midwater species are often sampled by a modified otter trawl (beam trawl) system.

Because many pollutants concentrate in sediments, bottom trawling is useful in collecting organisms that are associated with sediments. This sampling method can be used to collect specimens for tissue analysis or for ecological surveys to describe comparative populations (i.e., potentially impacted area versus reference area). However, there are limitations to using trawls to describe the entire population because some species are able to avoid being captured in the net.

Otter trawls are composed of two rectangular "otter boards" attached to the forward end of each side of the net. These boards are used to hold the mouth of the net open. The opening of the smaller trawls is about 16 to 20 feet. The length of line used to fish the trawl depends on the depth of the body of water. The preferred angle on the line is at least 5 feet of line per foot of depth. The net is a semi-balloon modified shrimp trawl with .75-inch mesh, and it often has an additional liner of .25-inch mesh in the end of the net (cod end) to retain smaller fish. The bottom line of the net mouth is a lead line to keep the net fishing the bottom, and the top line includes floats to keep the net open.

Small trawls can be operated by two people in a medium-sized power boat. While the trawl can be hauled in by hand, a winch is more useful, especially when the catch is expected to be large.

The length of time for fishing with the trawl depends on the expected abundance of organisms. The time usually varies from 5 to 15 minutes and begins when the net starts fishing the bottom. After the net is hauled back on deck, specimens collected are handled as appropriate for the study program. A detailed discussion of fish handling and preservation techniques used in the field is included in Subsection D5 (Target Fish Species) of this appendix.

Other miscellaneous gear includes life jackets, wet-weather gear (even in dry weather), gloves, and containers to hold the catch into for sorting and examination. Before collecting fish with bottom trawls, some information is required to determine expected sediment contamination levels. Personal protective gear is used when necessary.

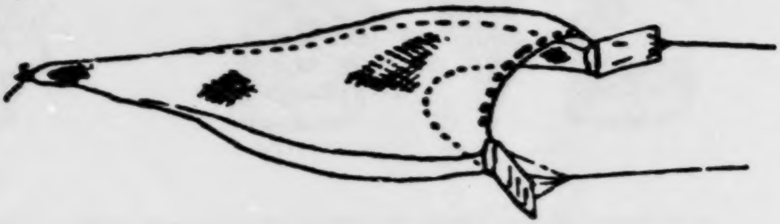
## D2. Electrofishing

Electrofishing is a freshwater fish sampling method that uses a pulsating direct current (DC) electroshocker, which stuns fish when the electric current travels through water with a resistance between 300 ohms and 30,000 ohms. Alternating current (AC) or nonpulsing DC methods are available but are not as desirable because higher fish mortality occurs with AC. Pulsating DC often gives better results than nonpulsing DC (Smith-Root, n.d.).

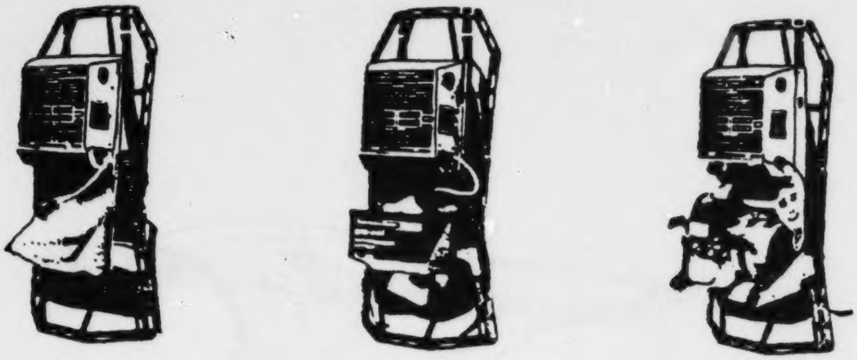
Electrofishers can readily be used to collect specimens for tissue analysis or to obtain population estimates or other population factors for creeks or small rivers in ecological surveys. When using electrofishing in ecological studies, several factors should be considered. These include size selectivity (larger fish

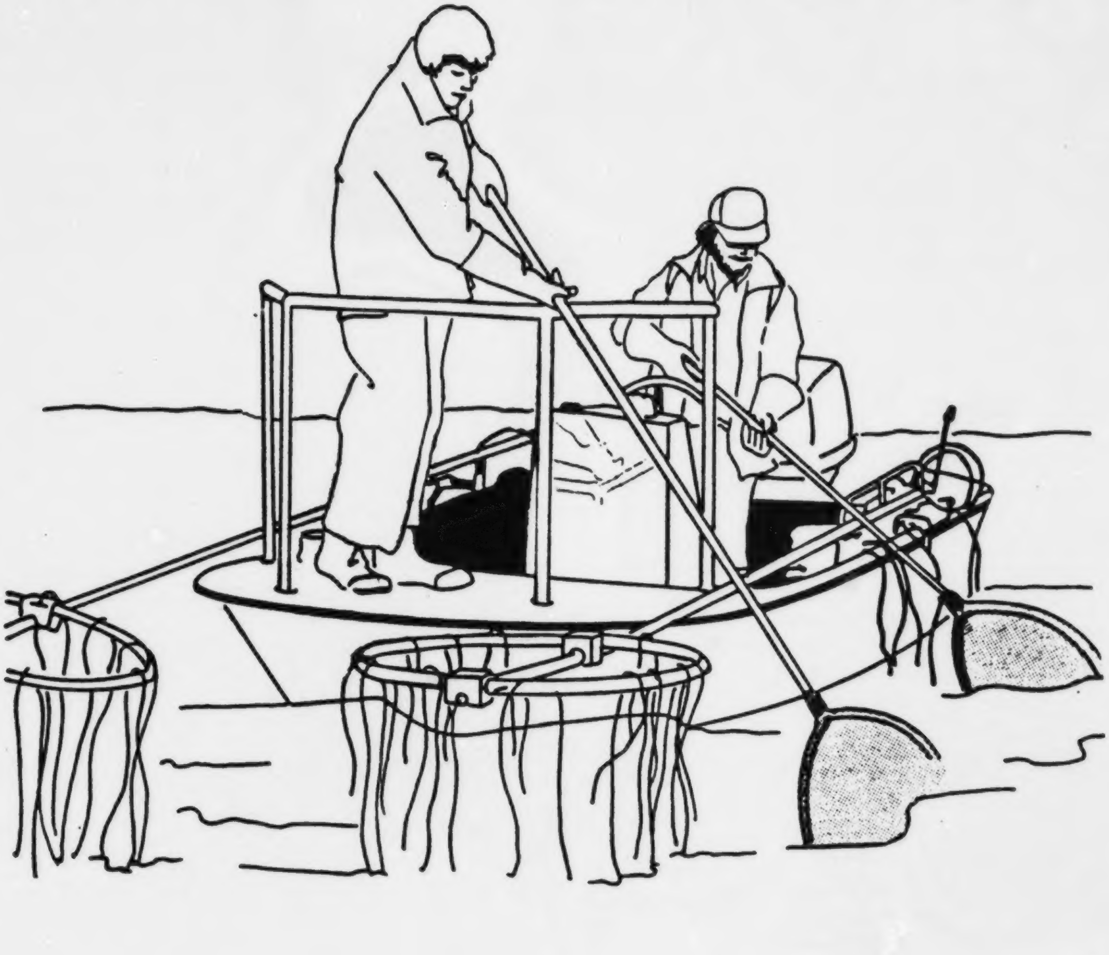
**Exhibit 12A-6**

## OTTER TRAWL



## Exhibit 12A-7
## BACKPACK AND BOAT ELECTROSHOCKERS





are more easily stunned than smaller fish); behavioral and habitat preference differences between species; and water conductivity, temperature, depth, and turbidity.

Electrofishing in creeks and small rivers can be done with a backpacking model pulsating DC electroshocker (top of Exhibit 12A-7). The backpacker system includes the electroshocker control unit and a 12-volt battery mounted in a specially designed backpack unit, the anode pole, and the cathode screens. The circular anode unit is mounted on a pole, which can be outfitted with a small mesh net to capture stunned fish. Other gear needed includes a long-handled, fine-mesh dip net to capture fish and a bucket to hold specimens. Because electroshockers have a high-voltage output, other important equipment includes nonleaking, chest-high wading boots and nonleaking rubber electrician's gloves with long cuffs. Life jackets are also worn.

Waters that cannot be waded in can be electrofished by boat (Exhibit 12A-7). The anode is clamped rigidly ahead of the boat and extends into the water. One person guides the boat with oars or a motor while one or two operators dip stunned fish. In waters too deep to wade, larger fish are more often taken by the boat method rather than by the backpack method. The same safety equipment is used in boat electro shocking as for the backpack method. The boat electroshocker is equipped with a "dead man" switch that allows for a quick disconnect of the electrical impulse if a person falls in the water.

Some knowledge of expected species and their suitable habitat is helpful in electrofishing. When stunned with a DC system, a fish will often be drawn toward the anode. However, in running waters, it can be swept downstream. Polarized dark glasses can aid in finding stunned fish. Collected organisms are placed in a water-filled bucket until processing can take place. Organisms to be used for tissue analysis are processed as described in Subsection D5 (Target Fish Species) of this appendix.

### D3. Seining

Seining involves the use of a long strip of netting hung between a float line and a lead-weighted line that is pulled through the water either by boat or, in shallow waters, by hand. This method is most often used in shallow sandy beach areas in either fresh or salt water. Beach seining is a simple sampling method that can collect fish samples for tissue analysis and can provide some information on species variability in ecological studies. Because certain sizes and types of fish can easily escape a beach seine, its use in ecological studies is limited.

A small beach seine consists of a nylon net equipped with cork or plastic floats on the top and a lead- or steel-weighted line on the bottom. The size of the net will depend on the area to be sampled, but a typical size is approximately 10 meters long and 3 meters deep. Mesh size can vary with the species of interest. Hauling lines are attached to the top and bottom lines by a short bridle. This type of small seine can be operated by two people. If the water is shallow, no boat is needed. One person anchors one side of the seine on the beach, while the other deploys the seine through the area to be fished. Both ends are then pulled on shore as quickly as possible, making sure that the bottom line remains on the bottom. Collected organisms are processed according to the study plan using techniques as described in Subsection D5—Target Fish Species of this appendix.

### D4. Hook and Line

Fishing with a hook and line involves the use of a hand-held rod or trolling baited hooks or other lures. While this method is not usually acceptable in ecological surveys, it is often the best way to obtain a few specimens for chemical analysis when other methods are not possible. Occasionally, fish freshly caught by nonstudy-team personnel are used in tissue analysis studies if enough information is known regarding the location of catch. This study can also provide information regarding human consumption of local species.

## D5. In Situ Bioassay

Local fish species can be used in field bioassays in the same manner as was described for macroinvertebrates in Subsection C3 of this appendix.

### Target Fish Species

Before sampling fish for tissue analysis, the study team identifies possible target species based on the following:

- Geographic location
- Available habitat
- Ease of capture and identification
- Pollution tolerance
- Use as a sport fish
- Nonmigratory habits

Exhibit 12A-8 lists possible target species by geographic location. While trout are identified as one of the preferred target fish species, caution is exercised in using these fish because in many areas, especially in the east, trout are stocked on a "put and take" basis. The local agency responsible for stocking can be contacted to determine when fish were stocked in a particular area. A period of 3 months is considered to be the minimum time span for trout to acquire a reasonable concentration of ambient pollutants (Freed et al., 1980).

The season during which fish are collected for tissue analysis is also an important consideration. The spawning season should be avoided whenever possible because fish are often stressed during this time; they also have different feeding habits, fat content, and respiration rates, which can influence pollutant uptake and clearing.

# Exhibit 12A-8
# TARGET FISH SPECIES FOR USE IN TISSUE ANALYSIS

## I. Target Species (East of Appalachian Mountains)

***Brook Trout *(Salvelinus fontinalis)*
***Small Mouth Bass (*Micropterus dolomieui)*
***Large Mouth Bass *(Micropterus salmoides*)
***Channel Catfish (*Ictalurus punctatus)*
**Brown Trout (*Salmo trutta*)
**Rainbow Trout (*Salmo gairdneri*)
**Bluegill (*Lepomis macrochirus*)
**Pumpkinseed (*Lepomis gibbosus*)
**Black Crappie (*Pomoxis nigromaculatus)*
**Striped Bass *(Morone saxatilis)*
*Carp (*Cyprinus carpio*)

## II. Target Species (West of Appalachian Mountains and East of Rocky Mountains)

***Rainbow Trout (*Salmo gairdneri*)
***Brook Trout (*Salvelinus fontinalis*)
***Small Mouth Bass (*Micropterus dolomieui)*
***Large Mouth Bass (*Micropterus salmoides*)
***Channel Catfish (*Ictalurus punctatus)*
**Striped Bass (*Morone saxatilis)*
**Yellow Perch (*Perca flavescens*)
**Walleye (*Stizostedion vitreum*)
**Bluegill (*Lepomis macrochirus*)
*Brown Trout (*Salmo trutta)*
*Carp *(Cyprinus carpio)*

## III. Target Species (West of and Including Rocky Mountains)

***Rainbow Trout (*Salmo gairdneri)*
***Brook Trout (*Salvenilus fontinalis)*
***Small Mouth Bass (*Micropterus dolomieui)*
***Large Mouth Bass (*Micropterus salmoides)*
***Channel Catfish (*Ictalurus punctatus)*
**Bluegill (*Lepomis macrochirus*)
**Striped Bass *(Morone saxatilis)*
*Cut-throat Trout (*Salmo clarki)*
*Brown Trout (*Salmo trutta)*
*Carp *(Cyprinus carpio)*

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*** Preferred target species
** Good target species
* Acceptable target species

Source: Freed et al., 1980.

# E. BIOLOGICAL FIELD SAMPLE PROCESSING AND PRESERVATION TECHNIQUES

## E1. Vegetation

Samples of vegetation collected from the site and intended for classification are initially placed in a ridged collector's box. Samples should be kept moist and may be refrigerated when the collector returns to the laboratory. After identification, samples may be pressed and mounted for permanent records.

Vegetation samples collected for tissue analysis are placed in 1-gallon paper bags and labeled. Information on the label includes the date, time, weather, collector, plant type, site, identification number, and proposed analysis.

The bag is stapled or clipped shut, labeled with the identification numbers, and placed in a larger plastic bag. Several paper bags may be necessary to collect 30 grams of material; 1 gram of plant tissue can suffice for most analyses that require the same analytical processing. However, more than 30 grams should be taken if multiple testing or other special processing are required. The plastic bag is then placed in a cooler with ice, ice packs, or dry ice. Care is taken to keep cooler water from contacting collected plant material. Samples remain in coolers for shipment.

## E2. Terrestrial Vertebrates

Once the specimens are collected, organisms to be used for tissue analysis are killed. Each animal is described by weight, measurement, sex, and other general items. All specimens are photographed. The following tissues can be removed using stainless steel scalpels: muscle and associated fatty deposits (lipids), liver, kidneys, and possibly hair and claw samples for metal analysis. Stomach or crop contents can be removed and preserved for identification. Any anomalies are noted and photographed. Sections of the anomalous tissues may be taken for analysis. Tissues are immediately wrapped in cleaned aluminum foil (dull side in), labeled, and frozen in the field using dry ice. Hair and claw samples are placed in plastic bags and labeled. Tissue samples are kept frozen until they are delivered to the laboratory. Surgical gloves are used during the dissecting process.

## E3. Aquatic Macroinvertebrates

Invertebrates collected for tissue analysis are sorted by species, counted, measured (when appropriate), and weighed to assure that each single sample consists of at least 100 grams. Crustaceans are washed using distilled water to remove particulate matter, either wrapped in cleaned aluminum foil (dull side in) or placed in Contract Laboratory Program cleaned glass vials, labeled, and frozen using dry ice. Samples are packed in ice chests and kept frozen until they are delivered to the laboratory. Bivalve mollusks are removed from their shells with a stainless steel knife for the examination of organochlorine compounds or with a plastic knife for the examination of metals. Tissues are purged using distilled water, wrapped in aluminum foil (dull side in), labeled, and frozen as described above. For organic analysis, organic-free water and blanks should be employed to document contamination control. Surgical gloves are worn while handling invertebrate samples. Glove manufacturers should be contacted to determine if gloves are a source of contamination and, if so, what compounds are typical.

## Exhibit 12A-9
## FISH PROCESSING PROCEDURES

1. Wash fillet board and table with local water supply (river, lake, etc.). Distilled water may be used.

2.** Clean knives with acetone and wipe board and table with acetone rinse. Rinse all with local water supply or distilled water.

3. Rinse table and knives between specimens with distilled water; alternately, a previously cleaned knife (#2 above) can be used for each specimen.

4. Take scale sample just posterior of gill and place in scale envelope.

5. Take weight (kg) and length (mm), and record on data sheets.

6. Fillet according to Exhibit 12A-11.

7. Wrap fillets in aluminum foil, and secure with 2-inch masking tape.

   a. If large, individually
   b. If small, combine

8. Label package with

   a. Date and time of collection and preparation
   b. Location (river, lake, etc.)
   c. Species
   d. Sample number
   e. Project number
   f. Sampler's/preparer's name

9. Place in bag and store in ice chest with dry ice.

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**Note: If volatile analyses are required, acetone use is discouraged and methanol can be used as a substitute.

Source: Michigan Department of Natural Resources.

## Exhibit 12A-10
## FISH COLLECTION EQUIPMENT CHECKLIST

Fillet table (formica top with long legs)
Wrapping table (aluminum, folding)
Fillet knives (1 large and 1 small)
Steel
Clear plastic packaging bags
Garbage bags
Fillet boards--polycarbonate
Water bucket
Wash brush
Garbage pail--6-gallon plastic or wastebasket
Data sheets
Procedure forms--fillet technique, skin-on or skin-off
Plastic bag ties
Scissors
2-inch masking tape
Marking pens and pencil
24-inch-wide roll of heavy-duty aluminum foil
Fish-scale envelope
Tripod
Fish-spring scale
Fish-measuring board
Ice chests
Paper towels
Acetone (wash bottle)**
Dry ice

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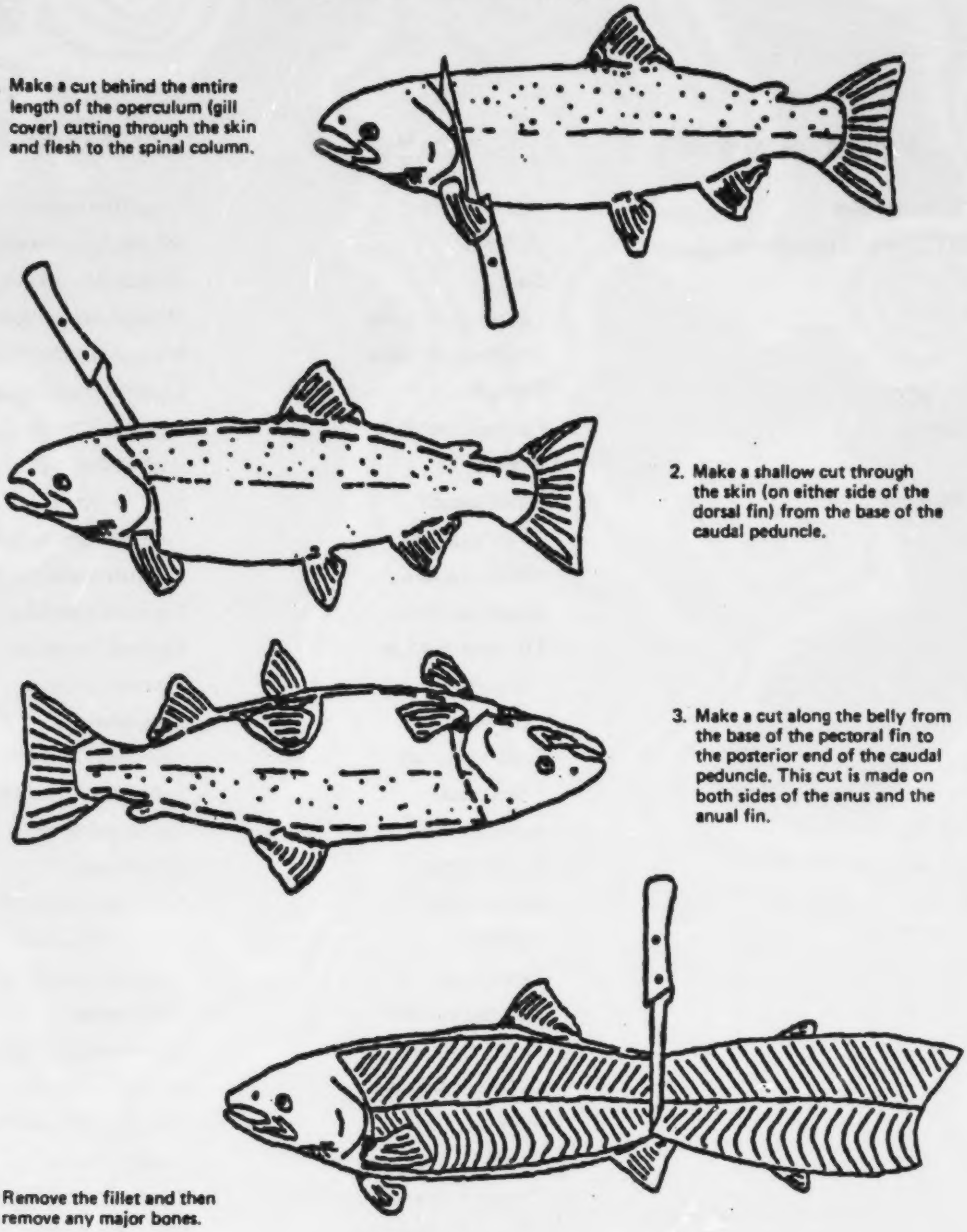
**May need to substitute methanol (see Exhibit 12-9).

Source: Michigan Department of Natural Resources.

**Exhibit 12A-11**
**PREPARATION OF "STANDARD FILLETS"**



1. Make a cut behind the entire length of the operculum (gill cover) cutting through the skin and flesh to the spinal column.
2. Make a shallow cut through the skin (on either side of the dorsal fin) from the base of the caudal peduncle.
3. Make a cut along the belly from the base of the pectoral fin to the posterior end of the caudal peduncle. This cut is made on both sides of the anus and the anual fin.
4. Remove the fillet and then remove any major bones.

## Exhibit 12A-12
## STANDARD EDIBLE PORTIONS OF SELECTED SPORT AND COMMERCIAL FISH

| Standard Edible Portion | Common Names | Scientific Name |
|---|---|---|
| Skin-on Fillet | Yellow perch | *Perca flavescens* |
| (all below to next heading) | Walleye | *Stizostedion vitreum* |
| | Sauger | *Stizostedion canadense* |
| | Largemouth bass | *Micropterus salmoides* |
| | Smallmouth bass | *Micropterus dolomieui* |
| | Bluegill | *Lepomis macrochirus* |
| Skin-on | Pumpkinseed | *Lepomis gibbosus* |
| | Rock bass | *Ambloplites rupestris* |
| Fillet | White perch | *Morone americana* |
| | Black crappie | *Pomoxis nigromaculatus* |
| | White crappie | *Pomoxis annularis* |
| | Green sunfish | *Lepomis cyanellus* |
| | Longear sunfish | *Lepomis megalotis* |
| | Warmouth | *Lepomis gulosus* |
| | Sucker family | *Catostomidae* |
| | Lake whitefish | *Coregonus clupeaformis* |
| | Lake trout | *Salvelinus namaycush* |
| | Rainbow trout | *Salmo gairdneri* |
| | Brown trout | *Salmo trutta* |
| | Brook trout | *Salvelines fontinalis* |
| | Splake | *Salvelinus poticalis** |
| | Lake trout | *Salvelinus namaycush* |
| | Atlantic salmon | *Salmo salar* |
| | Coho salmon | *Oncorhynchus kisutch* |
| | Chinook salmon | *Oncorhynchus tshawytscha* |
| | Pink salmon | *Oncorhynchus gorbuscha* |
| | Black bullhead** | *Ictalurus melas* |
| | Brown bullhead** | *Ictalurus nebulosus* |
| | Yellow bullhead** | *Ictalurus natalis* |
| | Channel catfish | *Ictalurus punctatus* |
| | Muskellunge | *Esox masquinongy* |
| | Northern pike | *Esox lucius* |
| | Round whitefish | *Prosopium cylindraceum* |

**Exhibit 12A-12**
**(continued)**

| Standard Edible Portion | Common Names | Scientific Name |
|---|---|---|
| Skin-off Fillet<br>(all below to next heading) | Lake herring (cisce) | *Coregonus artedii* |
| | Chubs (bloater) | *Coregonus hoyi* |
| | Carp | *Cyprinus carpio* |
| | Freshwater drum | *Aplodinotus grunniens* |
| | Bigmouth buffalo | *Ictiobus cyprinellus* |
| | Burbot | *Lota lota* |
| | Quillback | *Carpiodes cyprinus* |
| | Lake sturgeon | *Acipenser fulvescens* |
| Headless, gutted, whole fish | Rainbow smelt | *Osmerus mordax* |

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* Hybrids between brook trout (S. fontinalis) and lake trout (S. namaycush) are known as splake.

**Depending on local consumptive practice, bullheads may be considered "skin-off" species since they are skinned before consumption.

Source: Modified from Michigan Department of Natural Resources.

Invertebrates collected for ecological assessment are preserved in the field with either a 4- to 7-percent formalin solution (dependent on sample use and fragile nature of animals) or with 70-percent buffered ethanol. Each sample is labeled with sampling location, depth, sample number, species (or lowest taxonomic level practicable), number of individual organisms collected, sampling method, date, project number, sampler, and team leader.

## E4. Fish

Fish collected for tissue analysis are handled according to procedures outlined in the Michigan Department of Natural Resources (MDNR) Fish Processing Procedures (Exhibit 12A-9) and in the Field Collection Equipment Checklist (Exhibit 12A-10). Exhibit 12A-11 shows the procedure for preparation of MDNR's "standard fillets," and Exhibit 12A-12 lists the standard edible portions of selected sport and commercial fish. Any marine fish that may be associated with a hazardous waste site and is not on this list will require input from local individuals as to which tissues are consumed. Other fish tissues (i.e., liver, bone, etc.) may need to be analyzed depending on contaminants involved and where they may accumulate.

# SECTION 13

# SPECIALIZED SAMPLING TECHNIQUES

## 13.0 GENERAL

This section discusses several specialized sampling techniques that have been used by contractors on hazardous waste sites. The reader may develop other techniques for specific site needs. In those cases and in cases where the techniques listed here are modified for use on a specific site, careful documentation of the exact procedures used should be provided. This section does not discuss analytical techniques, since analytical methods would vary depending on the data quality objectives, the compounds of concern, the media, and the exact sampling technique. The Contract Laboratory Program plans to issue a "Field Methodology Catalog" in the summer of 1987 that will contain field analytical techniques suitable for analyses of the samples collected by using the techniques in this section.

## 13.1 WIPE SAMPLING

### 13.1.1 Scope and Purpose

This guideline discusses the steps required for obtaining a wipe sample. Wipe samples may be used to document the presence of carcinogenic substances or other toxic materials. In addition, wipe sampling is commonly used to ascertain that site or equipment decontamination has been acceptably effective.

### 13.1.2 Definitions

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. This person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

**Wipe Sample**

A sample used to assess surface contamination. The terms "wipe sample," "swipe sample," and "smear sample" have all been used synonymously. For purposes of this section, the sample will be termed "wipe sample."

### 13.1.3 Applicability

This guideline is applicable when a sample of the substances on a surface is needed. Surfaces may include walls, floors, ceilings, desk tops, equipment, or other large objects that are potentially contaminated.

### 13.1.4 Responsibilities

The SM or designee is responsible for deciding when wipe sampling is needed.

Field personnel are responsible for performing the actual sampling, maintaining sample integrity, and preparing the proper chain-of-custody forms.

### 13.1.5 Records

Records of wipe sampling include completed chain-of-custody forms and appropriate entries in the field logbook. If the sample collected is to be analyzed using the National Contract Laboratory Program (CLP), then CLP forms must be completed as discussed in Section 5.

### 13.1.6 Procedures

Wipe sampling can be an integral part of the overall sampling program. Wipe sampling can help to provide a picture of contaminants that exist on the surface of drums, tanks, equipment, or buildings on a hazardous waste site or that exist in the homes of a populace at risk.

Wipe sampling consists of rubbing a moistened filter paper over a measured area of 100 $cm^2$ to 1 $m^2$. The paper is then sent to the laboratory for analysis. The results are related back to the known area of the sample. A proper sampling procedure is essential to ensure a representative, uncontaminated sample.

#### 13.1.6.1 Equipment Required

The following equipment is needed for wipe sampling:

- Whatman 541 filter paper or equivalent, 15 cm
- Disposable, chemical-protective gloves
- Solvent to wet filter paper

#### 13.1.6.2 Wipe Sampling Steps

The steps involved in obtaining a wipe sample are listed below:

- Using a clean, impervious disposable glove, such as a surgeon's glove, remove a filter paper from the box. (**Note:** Although it is necessary to change the glove if it touches the surface being wiped, a new glove should be used for each sample to avoid cross contamination of samples. A new glove should always be used when collecting a new sample.)
- Moisten the filter with a collection medium selected to dissolve the contaminants of concern as specified in the sampling plan. Typically, organic-free water or the solvent used in analysis is used. The filter should be wet but not dripping.
- Thoroughly wipe approximately 1 $m^2$ of the area with the moistened filter. Using a 1 $m^2$ stencil will help in judging the size of the wipe area. If a different size area is wiped, record the change in the field logbook. If the surface is not flat, be sure to wipe any crevices or depressions.

- Without allowing the filter to contact any other surface, fold it with the exposed side in, and then fold it over to form a 90-degree angle in the center of the filter.

- Place the filter (angle first) into a clean glass jar, replace the top, seal the jar according to quality assurance requirements, and send the sample to the appropriate laboratory.

- Prepare a blank by moistening a filter with the collection medium. Place the blank in a separate jar, and submit it with the other samples.

- Document the sample collection in the field logbook and on appropriate forms, and ship samples per procedures listed in Section 6.

### 13.1.7 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revision to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 13.1.8 Information Sources

EBASCO. "Dioxin Sampling." *REM III Program Guidelines.* Prepared for U.S. Environmental Protection Agency. 28 February 1986.

NUS Corporation. "Site-Specific Site Operations Plans." REM/FIT Contract.

## 13.2 HUMAN HABITATION SAMPLING

### 13.2.1 Scope and Purpose

This subsection provides general guidance for the planning, method selection, and implementation of sampling activities used to determine the potential for human exposure to contaminants that are present in residential environment.

### 13.2.2 Definitions

**Human Habitation Areas**

Any place people may spend extended periods of time, such as their homes or offices.

### 13.2.3 Applicability

This subsection discusses sampling techniques that are similar in collection methodology to other types of samples, such as environmental soil and water, but are biased to emphasize potential human exposure to contaminants moving into the residential environment.

### 13.2.4 Responsibilities

Human habitation sampling is the most sensitive of all environmental sampling activities. This sensitivity must be addressed by community relations, health and safety, and sample collection personnel and should be their key responsibilities. Community relations personnel must coordinate with the EPA to gain site access for the samplers by care fully informing the residents of activities being performed and by answering any questions the residents might ask. This difficult task must be performed in a manner that will not overly alarm or excite people before definitive data can be collected to determine the true exposure assessment.

The health and safety (risk assessment) personnel must be responsible for informing management and community relations personnel of the potential exposure risks. Health and safety personnel will assist in sample plan preparation and will aid the community relations personnel in correctly answering questions. The risk assessment is also used in determining safety measures for samplers. Later the health and safety personnel will use the analytical data to make a final health risk assessment. Finally, the sampling personnel, aside from their normal responsibilities, must be made aware of the resident's perspective. Workers who are educated and more comfortable with hazardous environments must understand the potential health and economic impacts on the people involved and must conduct themselves in a comparable manner.

### 13.2.5 Records

Records generated during human habitation sampling will include telephone conversation notes, access permission slips, field notebooks, sample result databases, and quality assurance review documentation.

#### 13.2.5.1 Telephone Conversation Notes

As part of the initial community relations and site investigative activities, the EPA will make telephone calls to public officials, property owners, and other involved persons. These telephone conversations must be documented, taking care to note any commitments that are made or activities that are discussed. The EPA should make calls again just before sampling to reaffirm permission to sample.

#### 13.2.5.2 Access Permission Slips

A critical record that pertains to human habitation sampling activities is the property owner's consent to enter the property. Records such as these are important in the event that any litigation activities take place. Sampling personnel must be aware, however, that consent can be withdrawn at any time.

#### 13.2.5.3 Field Notebooks

Specific field records should be documented in accordance with the requirements set forth in the Quality Assurance Project Plan (QAPjP). (See Section 6.)

#### 13.2.5.4 Sample Results Databases

Human habitation sampling efforts will create sample result database records that are critical for health risk analysis and statistical evaluations.

#### 13.2.5.5 Quality Assurance Review Documentation

To ensure the quality, consistency, and completeness of the data, reports and other records generated must be reviewed by persons other than those involved with the record generation. Records documenting this review should be kept as a check against errors.

## 13.2.6 Procedures

This subsection describes several types of samples pertaining to human habitation. These samples can be related to the potential for human exposure to contaminants in the residential environment. Samples taken from the air in and near the house or from the lawn, gardens, swimming pools, crops, farm animals, and other media related to human habitation are collected generally in the same manner as other environmental samples. (See Sections 7, 8, 10, 11, and 12 of this compendium.)

#### 13.2.6.1 Vacuum Bag

If a vacuum cleaner is present in a residence being sampled, the vacuum bag can be an excellent source for a representative sample. The bag contains material from the air and home surfaces that may potentially expose humans through dermal, ingestion, and inhalation pathways. The vacuum bag should be removed from the vacuum and the sample collected as if it were a normal soil sample. Information on the period of use of the bag should be obtained.

#### 13.2.6.2 Air Conditioner Filter

If there is a central air conditioner or heating unit present in a residence, the filters used with the system are another source for collecting samples representative of the residential environment. Filters are removed and placed in large plastic bags for shipment to the laboratory for analysis. Information on the period of use of the filter(s) should be obtained.

#### 13.2.6.3 Dust Sweep

Dust sweep samples are applicable to residential sampling if an area exists where sufficient volume can be found. Areas such as attics, crawl spaces, basements, and garages are possible locations. Dust sweep samples are collected by sweeping dust into a pile and then transferring the dust to the sample containers by using an appropriate tool, such as a stainless steel spoon. Alternately, an industrial vacuum cleaner with a high-efficiency filter, such as used for asbestos removal, can be used. The sample volume needed will vary depending on the types of contaminants suspected. If only low-volume areas exist, surface wipe samples may be an alternative method. Infrequently dusted furniture (tall cabinets, refrigerator tops or coils, etc.) may be a good source.

#### 13.2.6.4 Sump or Drain Sediment

Sump or drain locations are potential sampling points for representative samples. The sediment that collects over a period of time, or backs up in the sump, is collected as a normal soil sample.

#### 13.2.6.5 Lint Traps

The lint traps in clothes washers and dryers may contain sufficient quantities of material for a sample. It is important to recognize that such material has been subjected to heat, water, and various laundry products.

### 13.2.7 Region-Specific Variances

Human habitation sampling should have a site-specific sampling plan, and all regions should be informed about current innovative developments. No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 13.2.8 Information Sources

NUS Corporation. *Superfund Training Manual*.

## 13.3 TCDD SAMPLING

### 13.3.1 Scope and Purpose

This subsection provides general information on performing 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD) analysis. The user should be aware that the procedures for use in sampling TCDD are often revised and should refer to the latest procedures. EPA Regional Sample Control Center (RSCC) should be contacted about preferred collection techniques.

### 13.3.2 Definitions

None.

### 13.3.3 Applicability

This sampling is applicable to sample collection work that deals with the collection and analysis of TCDD.

### 13.3.4 Responsibilities

The SM for a particular site or the designee is responsible for deciding when TCDD sampling is required.

Field personnel are responsible for performing the actual sampling, maintaining the sample integrity, and preparing the proper chain-of-custody forms.

## 13.3.5 Records

Records of TCDD sampling include chain-of-custody forms, TCDD sampling forms, and appropriate entries in the field logbook. Samples collected and sent to a CLP lab must be accompanied by the CLP forms discussed in Section 5.

## 13.3.6 Procedures

### 13.3.6.1 Sampling Activities

TCDD is usually sampled as a contaminant in soil or sediment. Because TCDD binds tightly to the soil, it is most often found in near-surface soils, unless the contaminated material was used as fill or consists of transported sediments. Sampling for TCDD in soils is similar to other types of soil sampling with the exception that a thorough blending of the sample is of greater importance and that the sampling equipment must be rigorously cleaned. Because the "action levels" associated with TCDD contamination are very low, the SM should consider using sampling equipment (stain less steel spoons, etc.) that has been cleaned in a laboratory using CLP procedures. The SM should dispose of the equipment after only one sample is taken. This greatly decreases the possibility of cross contamination.

### 13.3.6.2 Blending Procedure

Samples for TCDD must be properly blended before analysis. One technique involves using a 1-quart stainless steel blender cup. The blender cup should be no more than three-quarters full. Personnel should avoid placing stones in the blender cup. In addition, large clumps of soil should be broken up.

The sample is then returned to the blending station. The blender is placed on a sample drop sheet, and the following occurs:

- Pulse blender five times.
- Invert blender cup several times and shake.
- Repeat this procedure six times for a total of 30 pulses.
- Allow the blender to sit for 2 to 5 minutes to allow all dust to settle. The blended sample is then dispersed into a jar that has been placed in a plastic bag or "baggie" with a rubber band closure at the neck to reduce the possibility of contaminating the outside of the sample jar.

The sample is removed from the blender cup by using scoopulas, which will be disposed of when the sample jar has been filled. The baggie and rubber band are removed and put in the designated receptacle. The sample jar may be spray rinsed with 1,1,1-trichloroethane (1,1,1-TCE) to further reduce the possibility of contamination.

The jar is rebagged in a clean baggie, tagged, and processed for shipping.

Any material remaining in the blender cup is disposed of in the waste receptacle. The blender cup is filled (one- quarter to one-half full) with soapy water, agitated (blended) for 30 seconds, and, if necessary, scrubbed with a brush. The cup is then rinsed with distilled water, alcohol, and 1,1,1-TCE and allowed to drip dry.

#### 13.3.6.3 Field Quality Control Requirements

The quality control requirements listed below for dioxin sampling may be used.

- Do not composite field samples.
- Homogenize solid samples in the field using a mechanical blender or send an undisturbed sample to the laboratory for homogenization. Laboratory soil homogenization techniques are discussed in Subsection 13.6.
- Keep samples away from light.

For each batch of up to 20 samples from one site, the following samples should be added for quality control purposes to the shipment:

- Include two performance audit samples.
- Include one field blank composed of soil taken by field personnel from a clean area at the site.
- Add another field blank of soil that will be labeled on the bottle and on the packing list with "to be spiked by laboratory".
- Include one decontamination rinsate sample that was obtained from the last 1,1,1-TCE rinse of the blender. Label the bottle and packing list with "1,1,1-trichloroethane decontamination rinsate."

### 13.3.7 Region-Specific Variances

Sampling and blending techniques for TCDD vary from region to region. In Region III, each sample "batch" consists of 24 samples. The laboratory duplicates one analysis to bring the total number of results to 25. The QA samples included as part of each batch include the following:

- One field duplicate
- One field blank (actually background soil)
- One field background marked "to be spiked"
- One PE sample (selected and provided by the QA section after discussion with the SM or RPM)

If the number of samples is fewer than 19, an additional PE or duplicate may be added to the batch. Because variances become dated rapidly, the user should contact the EPA RPM for current variances and the RSCC for the latest procedures before initiating TCDD sampling. Other regional variances will be incorporated within Revision 01 of this document.

### 13.3.8 Information Sources

U.S. Environmental Protection Agency. "Engineering Support Branch Standard Operating Procedures and Quality Assurance Manual." Region IV, Environmental Services Division. 1 April 1986. (See Appendix 13-B.)

## 13.4 CONTAINER SAMPLING

### 13.4.1 Purpose and Scope

This subsection provides general information on available references for use in planning and implementing sampling programs involving the movement and opening of closed containers of sizes varying from bottles to large tanks. Collecting samples of containerized materials can be an important part of a field investigation. The samples are analyzed to determine the presence and magnitude of the threat to the environment.

### 13.4.2 Definitions

**Containers**
Any drum, bottle, can, bag, and the like, with a capacity of 120 gallons or less.

**Tanks**
Bulk tanks, such as railroad tank cars, and large above- and below-ground tanks with a capacity of more than 120 gallons including tank trailers.

### 13.4.3 Applicability

This guideline is applicable when a sample of the contents of a closed container is needed. In general, a container sampling program will have one of the following objectives:

- To determine the presence of hazardous materials onsite
- To characterize the range of materials onsite
- To characterize container contents for such purposes as bulking for disposal

### 13.4.4 Responsibilities

The SM or designee is responsible for deciding when container sampling is needed. Sampling personnel will be responsible for collecting representative samples, preserving sample integrity, and adhering to chain-of-custody procedures.

### 13.4.5 Records

Conditions, markings, and observations of containers found on a hazardous waste site, will be recorded in the site logbook. Chain-of-custody forms and the appropriate CLP forms will be completed. Photographs are important.

### 13.4.6 Procedures

Detailed procedures for closed-container sampling can be found in the following documents:

*Drum Handling Practices at Hazardous Waste Sites.* EPA Contract No. 68-03-3113. EPA/600/2-86/013. PB-86-165362. Cincinnati, Ohio. January 1986.

*Guidance Document for Cleanup of Surface Tank and Drum Sites.* OSWER Directive 9380.0-3. (NTIS PB-87-110672.) 28 May 1985.

"Drum Opening Techniques and Equipment" and "Containerized Liquids Sampling." *Sampling at Hazardous Materials Incidents.* EPA Training Manual. Cincinnati, Ohio.

NUS Corporation. "Drum Opening and Sampling." *NUS Operating Guidelines Manual.* Procedure No. 4.28.

Camp Dresser & McKee Inc. *Site Investigation Procedures Manual.* Vol. III. EPA Contract No. 68-01-6939. Document Control No. 999-PM1-IO-BRNL-1.- 1985.

# SECTION 14

# LAND SURVEYING, AERIAL PHOTOGRAPHY, AND MAPPING

## 14.1 SCOPE AND PURPOSE

This section provides information for use in the planning and implementation of land surveying, aerial photography, and mapping for hazardous waste sites.

## 14.2 DEFINITIONS

**Azimuth**
A horizontal direction expressed as an angular distance between the direction of a fixed point and the direction of the depth.

**Bearing**
The direction of one point with respect to another on the compass.

**Bench Mark**
A mark on a permanent object indicating elevation and serving as a reference in topographic surveys.

**Second (")**
The 60th part of a minute of angular measurement.

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. This person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

**Third-Order Plane Survey**
The lowest level of accuracy used in topographic mapping, usually limited to small-scale projects.

**Transit**
A theodolite with the telescope mounted so that it can be transited; a surveyor's instrument.

**Traverse**
A series of connected lines of known length related to one another by known angles.

## 14.3 APPLICABILITY

This section focuses on the methods of obtaining maps through field surveys, property surveys, surveys of monitoring wells, aerial photography, and photogrammetric mapping. In performing these methods, other survey requirements may need to be fulfilled (e.g., monument construction, boundary surveys, and time / method / accuracy / cost considerations of using an electronic distance meter instrument). Other surveying and mapping methods include plane table and alidade mapping, transit-stadia mapping, three-wire leveling, and trigonometric leveling. While these methods may have applications on a specific site, the methods discussed below apply to all mapping activities conducted for the U.S. EPA at hazardous waste sites.

## 14.4 RESPONSIBILITIES

It is the responsibility of the survey and mapping task leader to ensure that the proper techniques are followed throughout the project.

## 14.5 RECORDS

All field notes should be kept in bound books. Each book should have an index. Each page of field notes should be numbered and dated and should show the initials of all crew members. The person taking field notes will be identified in the log. Information on weather (wind speed / wind direction, cloud cover, etc.) and on other site conditions should also be entered in the notes. Graphite pencils or water proof ballpoint pens should be used. Erasing is not acceptable; use a single strike-through and initial it. The notekeeping format should conform to the *Handbook of Survey Notekeeping* by William Pafford. A survey work drawing with grid lines and at the scale of the topographic map should be prepared for all survey field work.

Aerial photography film annotation should include, at a minimum, the date of exposure, flight number, and exposure number. Additional information would include radar and barometric altitude, time, latitude, longitude, heading, pitch, roll, and drift angles.

Photogrammetric mapping should be in ink on mylar or scribed; maps should be 22 inches by 34 inches or as directed by the survey and mapping task leader.

## 14.6 PROCEDURES

### 14.6.1 Surveying – General

Survey requirements may necessitate survey accuracies of the third order; however, the second order may be required on some occasions and lower accuracies on other occasions. For the majority of sites, all surveys shall be third-order plane surveys as defined in the standards and specifications in Exhibit 14-1.

Third-order plane surveys and horizontal angular measurements should be made with a 20-second or better transit. Angles should be doubled, with the mean of the doubled angle within 10 seconds of the first angle. Distance measurements should be made with a calibrated tape corrected for temperature and tension or with a calibrated electronic distance meter instrument (EDMI). When using EDMI, the manufacturer's parts per million (ppm) error continues to be applied, as well as corrections for curvature and refraction.

#### 14.6.1.1 Third-Order Vertical Survey

Land surveys are to be completed by a surveyor who is licensed and registered in the state where the survey is conducted. When practical, vertical control will be referenced to the National Geodetic Vertical Datum (NGVD) of 1929, obtained from a permanent bench mark. If possible, level circuits should close on a bench mark whose elevation is known (other than the starting bench mark). If the circuit closes on the original bench mark, the last point in the circuit must be used as a turning point. The following criteria should be met in conducting the survey:

## Exhibit 14-1
## STANDARDS FOR THIRD-ORDER PLANE SURVEYS

**Principal Use:**

Small engineering projects and small-scale topographics mapping.

| | |
|---|---|
| Traverse | |
| Number of bearing courses between azimuth checks | 30 to 30 [30]* |
| Astronomical bearings: standard error of results | 8".0 [6".0]* |
| Azimuth closure at azimuth checkpoint not to exceed (use the smaller value) | 30" $\sqrt{N}$ or 8".0 per [20" $\sqrt{N}$]* station |
| Standard error of the mean for length measurements | 1 in 30,000 [1 in 20,000]* |
| Position closure per loop in feet after azimuth adjustment | 1:5,000 checkpoint or 3.34 $\sqrt{M}$, whichever is smaller |
| Leveling | |
| Levels of error of closure per loop in feet | 0.05 $\sqrt{M}$ |

*Figures in brackets are commonly used in preparing specifications for bid.

$N$ = then number of stations for carrying bearing
$M$ = the distance in miles

- Instruments should be pegged regularly.
- Rod levels should be used.
- Foresight and backsight distances should be reasonably balanced.
- No side shot should be used as a turning point in any level loop.
- Elevation readings should be recorded to 0.01 foot and estimated to 0.005 foot using a calibrated rod.

Temporary monuments should be set and referenced for future recovery. All monuments should be described in the field notes and should consist of a permanent mark scribed on facilities such as sidewalks, paved roads, or curbs. Sufficient description should be provided to facilitate their recovery. .

### 14.6.1.2 Property Surveys

All property surveys should be performed in accordance with good land surveying practices and should conform to all pertinent federal and state laws and regulations governing land surveying in the area where the work is being accomplished. The surveyor shall be licensed and registered in the state where the survey is conducted.

Upon completion of the project, all original field note books, computations, and pertinent reference materials should be delivered to the SM for retention in the site file. The surveyor may keep photostatic copies of the material.

All field note reductions should be checked and marked in such a way that a visual inspection of the field notes will confirm that checks have been made. All office entries in field notebooks should be made in colored pencil.

The office worker who reduces or checks field notes should initial each page worked on in the color used on that page.

### 14.6.1.3 Traverse Computations and Adjustments

Traverses will be closed and adjusted in the following manner:

- Step one – Bearing closures will be computed and adjusted if within limits.
- Step two – Coordinate closures will be computed using adjusted bearings and unadjusted field distances.
- Step three – Coordinate positions will be adjusted if the traverse closes within the specified limits. The method of adjusting shall be determined by the surveyor.
- Step four – Final adjusted coordinates will be labeled as "adjusted coordinates." Field coordinates should be specifically identified as such.

- Step five–The direction and length of the unadjusted error of closure, the ratio of error over traverse length, and the method of adjustment should be printed with the final adjusted coordinates.

#### 14.6.1.4 Level Circuit Computations and Adjustments

Level circuits will be closed and adjusted in the following manner:

- For a single circuit, elevations will be adjusted proportionally, provided the raw closure is within the prescribed limits for that circuit.
- In a level net where the elevation of a point is established by more than one circuit, the method of adjustment should consider the length of each circuit, the closure of each circuit, and the combined effect of all the separate circuit closures on the total net adjustment.

#### 14.6.1.5 Monitoring Well Surveys

Monitoring well locations are surveyed only after the installation of the tamperproof locking cap well casing cover, which is set in concrete. The horizontal plane survey accuracy is ±1 foot (unless greater accuracy is desired) and is measured to any point on the well casing cover. The vertical plane survey must be accurate to ±0.01 foot. Three elevations are measured, including the following:

- Top of the inner well casing (on the lip)
- Top of the outer protective casing (on the lip, not the cap)
- Finished concrete pad adjacent to the outer well casing

The point at which the elevation was measured should be scribed so that water level measurements may be taken at the same location. **Note:** The SM should ensure that the surveying party is given the keys to the locking cap before starting the survey.

### 14.6.2 Aerial Photography

Aerial photography for nonphotogrammetic use can be obtained from the following agencies:

- Environmental Monitoring System Laboratory (EMSL), Las Vegas, Nevada
- Environmental Photographic Interpretation Center (EPIC), Warrenton, Virginia
- National Cartographic Information Center, Reston, Virginia
- Soil Conservation Service, U.S. Department of Agriculture; Eastern or Western Laboratory, Asheville, North Carolina, or Salt Lake City, Utah, respectively

- Forest Service, U.S. Department of Agriculture, Washington, D.C. (for the eastern United States and Alaska), or the appropriate regional forester in Forest Service Regions 1-6 (Montana, Colorado, New Mexico, Utah, San Francisco, and Portland)

State and local transportation departments, zoning commissions, and planning divisions or local universities may also have useful aerial photographs. The EPA Enviropod, which consists of two 70-mm cameras mounted in a pod that can be attached to a light plane, is available through EPA regional offices. Aerial photographs may be obtained rapidly using the Enviropod and EPA photographic laboratories for developing the film. The photographs are not suitable for photogrammetric use. Photogrammetric aerial photography is usually contracted.

### 14.6.2.1 Contracting Aerial Photography

The following provisions should be included in the contract:

- **Business Arrangements**—These include such items as the cost of the aerial survey, posting of a performance bond, assumption of risks and damages, provision for periodic inspection of work, reflights, cancellation privileges, schedule for delivery and payments, and ownership and storage of negatives.
- **Area to be Photographed**—This includes location, size, and boundaries. These are ordinarily indicated on flight maps (1:24,000 scale) supplied by the purchaser.
- **Type of Photographic Film and Filter**—This includes such items as ASA exposure rating (ASA 100 is usually specified). The dimensional stability of the film base may also be specified.
- **Negative Scale**—The maximum scale deviation normally allowed is ±5 percent.
- **The Aerial Camera**—A National Bureau of Standards calibration report meeting U.S. Geological Survey standards for photogrammetric mapping is required. Other camera specifications include size of negative format, method of flattening film during exposure, type of shutter, focal length (usually 6 inches), distortion characteristics of the lens, and resolving power.
- **Position of Flight Lines**—Lines are to be parallel, oriented in the correct compass direction, and within a stated distance from positions drawn on flight maps.
- **Overlap**—This is usually set at 55 to 65 percent (the average is 60 percent) along the line of flight and 15 to 45 percent (the average is 30 percent) between adjacent lines. At the ends of each flight line, two photo centers should fall outside the boundary of the tract.
- **Print Alignment**—Crab or drift is not to affect more than 10 percent of the print width for any three consecutive photographs.
- **Tilt**—This should not exceed 2 or 3 degrees for a single exposure, or average more than 1 degree for the entire project.
- **Time of Photography**—The season of the year and the time of day (or minimum sun angle) are usually specified. The aerial photography should be conducted in the spring or fall when deciduous vegetation is bare and the ground is essentially free of snow cover. Ideal flight times are between 10:00 a.m. and 2:00 p.m. local standard time, or when the sun is at a minimum of 30 degrees above the horizon. Cloud or fog cover should not exceed 10 percent.

- **Base Maps**—If base maps or radial line plots are required, responsibility for ground control (field surveying) should be established.

- **Film Processing**—Included here are procedures for developing and drying negatives and for indexing and editing film rolls, plus a description of the type of photographic paper (weight, finish, and contrast) to be used.

- **Quality of Negatives and Prints**—Negatives and prints should be free from stains, scratches, and blemishes that detract from the intended use.

- **Materials to be Delivered**—Two sets of contact prints and one set of index sheets are usually supplied. A copy of the original flight log may also be specified. Additional items such as enlargements, mosaics, maps, or plan -and profile sheets should be listed in detail. One set of contact prints should be delivered to the project manager within 5 days of the date of the photography, unless otherwise specified. The SM should arrange for additional sets of prints to be delivered at the same time if needed.

### 14.6.2.2 Photogrammetric Mapping

The scale of the mapping photography should be suitable for the preparation of a topographic map by photogrammetric methods at a scale and contour interval requested by the project, usually a 1" = 50' scale and 2-foot contour intervals. Larger areas or areas with great differences in elevation may require a different scale.

Map accuracy shall meet or exceed the following minimum standards:

- For horizontal accuracy, 90 percent of all defined points should be within 1/ 40 inch of their true position, and 100 percent of all defined points should be within 1/ 20 inch of their true position.

- For vertical accuracy, 90 percent of all contours shall be within one-half of a contour interval, and 100 percent of all contours shall be within one contour interval. Ninety percent of all spot elevations should be accurate to within one-fourth of the contour interval, and all spot elevations should be within one-half of the contour interval.

- Mapping should show all planimetric features including, but not limited to, buildings, walks, roads, fences, ditches, trees, utility poles, tanks, drums, lagoons, pits, ponds, and other such features visible on the photograph, as well as contours and spot elevations on roads, dikes, and ditch inverts. Assemblages of containers (e.g., drums, laboratory bottles) may be indicated by a symbol rather than by depicting individual containers. The height and estimated number of such containers should be depicted within the symbol.

- All horizontal and vertical control points should be shown on the final map along with a tabulation of coordinates and elevations. The description, origin, and elevations of the bench marks used for the mapping control should be shown on the map.

- The horizontal coordinate system should be referenced to a local recoverable baseline at the site. The state plane coordinate system should be used when it is readily available near the site.

- Photographic control points must be kept outside the hazardous areas where possible.

- The map should show the basis of bearing, north arrow, date of photography, names of streets and highways, project number, project name, and a bar scale.

### 14.6.3 Remote Sensing

**The standards for remote sensing imagery will be determined on a project specific and instrument-specific basis. Remote sensing data are used in environmental surveys and risk assessments. Methods include, but are not limited to, the following:**

- **Satellite photography (LANDSAT, Skylab)**
- **Radar (side-looking airborne radar, plan positive indicator)**
- **Thermal imagery (infrared detectors, line scanning, infrared photography)**
- **Multiband spectral imagery**
- **Low-altitude helicopter photography (stereograms)**
- **Continuous strip photography**

The National Cartographic Information Center (NCIC) provides information about and access to cartographic data generated by federal, state, and local governmental bodies and by private sources. NCIC does not hold these data; it functions as a link between the user and the desired material. Requests for information may be submitted to the following agency:

National Cartographic Information Center
U.S. Geological Survey
507 National Center
Reston, Virginia 22092

Records of aerial photographic coverage of the United States and outlying areas and of space imagery are maintained at the EROS Data Center in Sioux Falls, South Dakota. The Earth Resources Observation Systems (EROS) program gathers and uses remotely sensed data, collected by satellite and aircraft, of natural features and those made by humans on the earth's surface. Reference files, consisting of microfilms of available data primarily from LANDSAT I and II, formerly known as Earth Resources Technology Satellite (ERTS), may be viewed at 20 locations across the United States. Purchases of such data may be made from the following:

EROS Data Center
U.S. Geological Survey
Sioux Falls, South Dakota 57198

### 14.6.4 Hydrographic Surveys

Hydrographic surveys deal with the measurement and definition of the configuration of the bottom and adjacent land areas of oceans, lakes, rivers, harbors, and other bodies of water.

The size of the body of water will dictate the type of survey required to perform the necessary mapping. Surveys should conform to the requirements set forth in the *Hydrographic Survey Manual* by the U.S. Department of Commerce.

## 14.7 REGION-SPECIFIC VARIANCES

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

## 14.8 INFORMATION SOURCES

American Society of Photogrammetry. *Manual of Photogrammetry*y. 4th ed.

Averes, T. Eugene. *Interpretation of Aerial Photographs*. 2nd ed. Minneapolis, Minnesota: Burgens Publishing Company.

Federal Geodetic Control Committee. *Specification to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys*. July 1975. (Revised June 1980.)

*Manual of Photographic Interpretation*. Menasha, Wisconsin: Banta Publishing Company.

Moffitt, Francis H., and Harry Bouchard. *Surveying*. New York: Mtext Educational Publishers.

Pafford, William F. *Handbook of Survey Notekeeping*.

Umbach, Melvin J. *Hydrographic Survey Manual*. 4th ed. U.S. Department of Commerce, National Oceanographic and Atmospheric Administration.

# SECTION 15

# FIELD INSTRUMENTATION

## 15.0 INTRODUCTION

Section 15 provides basic information on operating various pieces of equipment that are typically used in the field. The purpose of this section is not to provide standard operating procedures or to establish performance criteria for field instruments. The purpose is to provide a narrative description of some instrument use approaches and techniques that have been tested on certain projects. In Fall 1987, the Contract Laboratory Program (CLP) will publish a "Field Screening Methods Catalog" that will contain detailed discussions of field analytical methods, including use of field instruments for analysis. The CLP catalog will provide a consolidated reference for use by EPA, contractors, state and local agencies, and potentially responsible parties (PRPs) who will be conducting field analysis. When this compendium is updated, it will reflect the information contained in the CLP catalog. The updated compendium will also contain information on any additional instruments that were found useful by contractors but were not included in the catalog. Field monitoring instruments are used whenever the data quality objectives specify Level I and II analytical support as adequate.

The objective of Level I analysis is to generate data that are generally used in refining sampling plans and in estimating the extent of contamination at the site. This type of support provides real-time data for health and safety purposes. Additional data that can be obtained effectively by Level I analyses include pH, conductivity, temperature, salinity, and dissolved oxygen for water (see Sections 8 and 10), as well as some measurement of contamination using various kits (see Subsection 7.6).

Level I analyses are generally effective for total vapor readings using portable photoionization of flame ionization meters that respond to a variety of volatile inorganic and organic compounds (see Section 15).

Level I analysis provides data for onsite, real-time total vapor measurement, evaluation of existing conditions, refinement of sampling location, and health and safety evaluations. Data generated from Level I support are generally considered qualitative in nature, although limited quantitative data also can be generated. Data generated from this type of analysis provide the following:

- Identification of soil, water, air, and waste locations that have a high likelihood of showing contamination through subsequent analysis
- Real-time data to be used for health and safety consideration during site reconnaissance and subsequent intrusive activities
- Quantitative data if a contaminant is known and the instrument is calibrated to that substance

On the other hand, field analysis (see Section 7) involves the use of portable or transportable instruments that are based at or near a sampling site. Field analysis should not be confused with the process of obtaining total organic readings using portable meters. These instruments typically are used in obtaining data that is defined by data quantity objectives as Level I. (See Section 7 for a discussion of DQO data levels.) The analytical techniques associated with these instruments are derived from the experiences of a number of contractors and EPA personnel.

Equipment users also should consult the applicable manufacturer's operating manuals, which will provide a more comprehensive guide to all facets of using field equipment. Several of the procedures discussed below refer to sections of the manufacturer's manual that are too voluminous to reproduce here. Finally, all equipment calibrations and readings that occur in the field must be recorded in the site-specific logbook.

Exhibit 15-1, modified from Tables 7-1 and 7-2 of "Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities," NIOSH / OSHA / USCG / EPA, October 1985, presents a summary of the characteristics of classes of instruments, specific examples of which are discussed in detail below.

## 15.1 PHOTOVAC 10A10

### 15.1.1 Scope and Purpose

Subsection 15.1 discusses the use, calibration, and maintenance of the Photovac 10A10.

### 15.1.2 Definitions

**Carrier Gas**
The gas used to transport a gaseous sample through the chromatographic column and on to the detector of a gas chromatograph. In the Photovac, the carrier gas is ultra-pure air.

**Photoionization Detector (PID)**
The detector uses an ultraviolet light source to ionize individual molecules that have an ionization potential less than or equal to that rated for the ultraviolet light source. Gaseous contaminants are ionized as they emerge from the column, and the ions are then attracted to an oppositely charged electrode, causing a current and finally an electric signal to the strip chart recorder.

**Retention Time**
The total time required for a volatile chemical to traverse and emerge from chromatographic column into the detector, measured from the time of injection onto the column.

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

**Standard**
This is a known concentration of a known chemical that is used to perform quantitative analysis. Either the chemical constituent(s) can be in a solution with distilled water so that a headspace is present, or it can be completely vaporized in the volatile organic analysis (VOA) vial. A syringe can be used to withdraw some of the headspace gas after the vial is agitated, and this gas can be injected into the column for chromatographic analysis. The retention times of the standard are then compared to the retention times of unknown peaks in a sample.

**Volatile Contaminants**
Chemicals that are characterized by low boiling points and high vapor pressures.

# Exhibit 15-1
# FIELD INSTRUMENTS

Exhibit 15-1
FIELD INSTRUMENTS*

| Instrument | Hazard Monitored | Application | Detection Method | Limitations | Ease of Operation | General Care and Maintenance | Typical Operating Times |
|---|---|---|---|---|---|---|---|
| Ultraviolet (UV) Photoionization Detector (PID)<br>(Photovac 10A10)<br>(HNU PI-101) | Many organic and some inorganic gases and vapors. | Detects total concentrations of many organic and some inorganic gases and vapors.<br>Some identification of compounds is possible if more than one probe is used. | Ionizes molecules using UV radiation; produces a current that is proportional to the number of ions. | Does not detect methane.<br>Does not detect a compound if the probe used has a lower energy level than the compound's ionization potential.<br>Response may change when gases are mixed.<br>Other voltage sources may interfere with measurements.<br>Readings can only be reported relative to the calibration standard used.<br>Response is affected by high humidity. | Effective use requires that the operator understands the operating principles and procedures, and is competent in calibrating, reading, and interpreting the instrument. | Recharge or replace battery.<br>Regularly clean and maintain the instrument and accessories. | 10 hours; 5 hours with strip chart recorder. |
| Flame Ionization Detector (FID) with Gas Chromatography Option<br>(OVA 128) | Many organic gases and vapors. | In survey mode, detects the total concentrations of many organic gases and vapors. In gas chromatography (GC) mode, identifies and measures specific compounds.<br>In survey mode, all the organic compounds are | Gases and vapors are ionized in a flame. A current is produced in proportion to the number of carbon atoms present. | Does not detect inorganic gases or some synthetics. Sensitivity depends on the compound.<br>Should not be used at temperatures less than 40°F (4°C)<br>Difficult to absolutely identify compounds. | Requires experience to interpret data correctly, especially in the GC mode.<br>Specific identification requires calibration with specific analyte of interest. | Recharge or replace battery.<br>Monitor fuel and/or combustion air supply gauges.<br>Perform routine maintenance as described in the manual.<br>Check for leaks. | 8 hours; 3 hours with strip chart recorder. |

## Exhibit 15-1
## (continued)

Exhibit 15-1
(continued)

| Instrument | Hazard Monitored | Application | Detection Method | Limitations | Ease of Operation | General Care and Maintenance | Typical Operating Times |
|---|---|---|---|---|---|---|---|
| | | are ionized and detected at the same time. In GC mode, volatile species are seperated. | | High concentrations of contaminants or oxygen-deficient atmospheres require system modification.<br>In survey mode, readings can be only reported relative to the calibration standard used. | | | |
| Combustible Gas Indicator (CGI)<br>(MSA Explosimeter) | Combustible gases and vapors. | Measures the concentration of a combustible gas or vapor. | A filament, usually made of platinum, is heated by burning the combustible gas or vapor.<br>The increase in heat is measured. | Accuracy depends, in on the difference between the the calibration and sampling temperatures.<br>Sensitivity is a function of the differences in the chemical and physical properties between the calibration gas and the gas being sampled.<br>The filament can be damaged by certain compounds such as silicones, halides, tetraethyl lead, and oxygen-enriched atmospheres.<br>CGI does not provide a valid reading under oxygen-deficient conditions. | Effective use requires that the operator understands the operating principles and procedures. | Recharge or replace battery.<br>Calibrate immediately before use. | Can be used for as long as the battery lasts, or for the recommended interval between calibration whichever is less. |

## Exhibit 15-1
## (continued)

Exhibit 15-1
(continued)

| Instrument | Hazard Monitored | Application | Detection Method | Limitations | Ease of Operation | General Care and Maintenance | Typical Operating Times |
|---|---|---|---|---|---|---|---|
| Oxygen Meter<br>(MSA Oxygen Meter) | Oxygen ($O_2$). | Measures the percentage of $O_2$ in air. | Uses an electrochemical sensor to measure the partial pressure of $O_2$ in the air and converts that reading to $O_2$ concentration. | Must be calibrated before use to compensate for altitude and barometric pressure.<br>Certain gases, especially oxidants such as ozone, can affect readings.<br>Carbon dioxide ($CO_2$) poisons the detector cell. | Effective use requires that operator understands the operating principles and procedures. | Replace detector cell according to manufacturer's recommendations.<br>Recharge or replace batteries before expiration of the specified interval.<br>If the ambient air is more than 0.5% $CO_2$, replace or rejuvenate the $O_2$ detector cell frequently. | 8 to 12 hours. |
| Direct-Reading Colorimetric Indicator Tube<br>(Draeger) | Specific gases and vapors. | The compound reacts with the indicator chemical in the tube, producing a stain whose length or color change is proportional to the compound's concentration. | The measured concentration of the same compound may vary among different manufacturer's tubes.<br>Many similar chemicals interfere.<br>Greatest sources of error are (1) how the operator judges stain's end-point and (2) the tube's limited accuracy.<br>Affected by high humidity. | Minimal operator training and expertise required. | Do not use a previously opened tube even if the indicator chemical is not stained.<br>Check pump for leaks before and after use.<br>Refrigerate before use to maintain shelf life of about 2 years.<br>Check expiration date of tubes.<br>Calibrate pump volume at least quarterly.<br>Avoid rough handling that may cause channeling. | | |

Exhibit 15-1
(continued)

| Instrument | Hazard Monitored | Application | Detection Method | Limitations | Ease of Operation | General Care and Maintenance | Typical Operating Times |
|---|---|---|---|---|---|---|---|
| Gamma Radiation Survey Instrument<br>(Thyac III) | Gamma radiation. | Environmental radiation monitor. | Scintillation detector. | Does not measure alpha or beta radiation. | Extremely easy to operate, but requires experience to interpret data.<br>Rugged, good in field use. | Must be calibrated annually at a specialized facility. | Can be used for as long as the battery lasts, or for the recommended interval between calibrations, whichever is less. |
| Portable Infrared (IR) Spectrophotometer | Many gases and vapors. | Measures concentration of many gases and vapors in air.<br>Designed to quantify one- or two-component mixtures. | Passes different frequencies of IR through the sample.<br>The frequencies adsorbed are specific for each compound. | In the field, must make repeated passes to achieve reliable results.<br>Requires 115-volt AC power.<br>Not approved for use in a potentially flammable or explosive atmosphere.<br>Interference by water vapor and carbon dioxide.<br>Certain vapors and high moisture may attach the instrument's optics, which must then be replaced. | Requires personnel with extensive experience in IR spectrophotometry. | As specified by manufacturer. | |

*Source: Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities, Tables 7-1 and 7-2, NIOSH/OSHA/USCG/EPA, October 1985.

### 15.1.3 Applicability

This procedure is applicable to Photovac 10A10s used for field and laboratory analysis.

### 15.1.4 Responsibilities

The SM is responsible for monitoring the implementation of these procedures.

### 15.1.5 Records

Training records, maintenance records, and calibration records will be generated and maintained by the responsible organization. Maintenance, calibration, and results obtained in the field will be recorded in the site logbook.

### 15.1.6 Procedures

Before beginning the set-up and operation of 10A10, the following precautions should be carefully reviewed. Because of its special capabilities, 10A10 requires special treatment.

1. NEVER remove the top panel with the instrument connected to the MAINS (electrical supply); always disconnect the instrument first because of the danger of electric shock.

2. The 10A10 must always be connected to the carrier gas supply, and a continuous stream of carrier gas must be passed through the column. This arrangement maintains the column in peak condition and ready for use with a minimum of delay.

3. NEVER inject liquid samples, however small, into the 10A10. It is an all-gas system and is not designed to accept liquids, which will cause gross contamination and necessitate a thorough overhaul.

4. Read carefully the section in the manufacturer's manual on battery care. Avoid overcharging the batteries; otherwise, their life will be impaired.

5. Except when charging batteries, always unplug the unit from the MAINS (electrical supply) when it is not in use.

6. When transferring the unit from extremely cold environments into warm, humid conditions, be alert to the likelihood of condensation; if possible, allow some time for the instrument to warm up before using.

7. Establish that the Photovac 10A10 can detect the contaminate being tested for (see Exhibit 15-2). Two criteria can be followed:

   a. The ionization potential of the compound must be less than 11 electron volts (eV).

b. The boiling point of the compound must allow for its elution through an ambient temperature column. Higher boiling points will not allow this to occur.

### 15.1.6.1 Startup Procedure

1. The preferred carrier gas is Linde Air Ultra Zero or its equivalent (with less than 0.1 ppm total organic contamination). Fit the supply cylinder with a high-quality, two-stage gas chromatograph (GC) regulator. Connect the regulator to the CARRIER IN fitting with 1/8-inch Teflon tubing and a brass, quick-disconnect fitting.

2. Set the flowrate to 10 ± 1 ml/min by adjusting the CARRIER FLOW adjustment. Make a note of the setting for future use. Check the flowrate by attaching a flow meter with 1 ml/min or better accuracy to the OUT gas fitting.

3. Check that the electrical controls are set as follows:

a. Move POWER SWITCH to OFF.

b. Move CHARGE SWITCH to OFF.

c. Move ATTENUATION SWITCH to 100 (least sensitive).

d. Move OFFSET dial to zero.

e. Connect chart recorder to the coaxial OUTPUT connector, using the lead provided.

f. Set the chart recorder to 100 mV full scale and chart speed to 2 cm/min.

g. Plug the POWER CORD into the panel socket and connect to the 115V 60 Hz AC supply; the red AC indicator light will come on.

The instrument is now in its POWER DOWN condition and is ready for starting.

4. With the chart recorder off, switch on the POWER switch. The red source OFF indicator may light and stay on for up to 5 minutes. During this time, the lamp-start sequence is being automatically initiated. If more than 5 minutes is required, an adjustment must be made to the screw next to the lamp (under the aluminum housing).

5. As soon as the SOURCE OFF light is extinguished, the meter will show a high reading that should fall rapidly as conditions in the photoionizing chamber stabilize. The reading should become steady after approximately 5 minutes.

6. Establish an acceptable baseline on the chart recorder.

7. The instrument is now ready for calibration and use.

8. The user may now make sample injections from 1 to 1,000 l (can be larger in certain situations, i.e., low-level air monitoring).

9. **Reminder:** NEVER inject liquid samples into the Photovac.

Exhibit 15-2

## SOME COMPOUNDS THAT CAN BE DETECTED USING THE PHOTOVAC 10S SERIES OF PORTABLE GCs

| | eV |
|---|---|
| Acetaldehyde | 10.21 |
| Acetic acid | 10.37 |
| Acetone | 9.69 |
| Acetylene | 11.41 |
| Acetylene dichloride | 9.80 |
| Acetylene tetrabromide | |
| Acrolein | 10.10 |
| Acrylonitrile | 10.91 |
| Allene | 9.83 |
| Allyl alcohol | 9.67 |
| Allyl chloride | 10.20 |
| Aminoethanol | 9.87 |
| Ammonia | 10.15 |
| Aniline | 7.70 |
| Anisole | 8.22 |
| Arsine | 9.89 |
| | |
| Benzaldehyde | 9.53 |
| Benzene | 9.25 |
| Benzenethiol | 8.33 |
| Benzyl chloride | 10.16 |
| Benzonitrile | 9.71 |
| Benzotrifluoride | 9.68 |
| Bromobenzene | 8.98 |
| 1-Bromobutane | 10.13 |
| 2-Bromobutane | 9.98 |
| 1-Bromobutanone | 9.54 |
| 1-Bromo-2-chloroethane | 10.63 |
| Bromochloromethane | 10.77 |
| Bromodichloromethane | |
| 1-Bromo-3-chloropropane | |
| Bromoethane | 10.28 |
| Bromoethene | 9.80 |
| Bromoform | 10.48 |
| 1-Bromo-3-hexanone | 9.26 |
| Bromoethane | 10.53 |
| Bromoethyl ethyl ether | 10.08 |
| 1-Bromo-2-methylpropane | 10.09 |
| 2-Bromo-2-methylpropane | 9.89 |
| 1-Bromopentane | 10.10 |
| 1-Bromopropane | 10.18 |
| 2-Bromopropane | 10.08 |
| 1-Bromopropene | 9.30 |
| 2-Bromopropene | 10.06 |
| 3-Bromopropene | 9.70 |
| 2-Bromothiophene | 8.63 |
| O-bromotoluene | 8.79 |
| M-bromotoluene | 8.81 |
| P- bromotoluene | 8.67 |
| 1,3-Butadiene | 9.07 |

| | eV |
|---|---|
| 2,3-Butadione | 9.23 |
| N-Butanal | 9.83 |
| 2-Butanal | 9.73 |
| N-Butane | 10.63 |
| 1-Butanethiol | 9.14 |
| 2-Butanone | 9.53 |
| Iso-butanol | 10.47 |
| Sec-butanol | 10.23 |
| Tert-butanol | 10.25 |
| 2-Butanol | 10.1 |
| 1-Butene | 9.58 |
| Cis-2-butene | 9.13 |
| Trans-2-butene | 9.13 |
| 3-Butene nitrile | 10.39 |
| N-butyl acetate | 10.01 |
| Sec-butyl acetate | 9.91 |
| N-butyl alcohol | 10.04 |
| N-butyl amine | 8.71 |
| I-butyl amine | 8.70 |
| S-butyl amine | 8.70 |
| T-butyl amine | 8.64 |
| N-butyl benzene | 8.69 |
| I-butyl benzene | 8.68 |
| T-butyl benzene | 8.68 |
| Butyl cellosolve | 8.68 |
| N-butyl mercaptan | 9.15 |
| I-butyl ethanoate | 9.95 |
| Iso-butyl mercaptan | 9.12 |
| I-butyl methanoate | 10.46 |
| 1-Butyne | 10.18 |
| 2-Butyne | 9.85 |
| N-butyraldehyde | 9.86 |
| | |
| Carbon disulfide | 10.13 |
| Carbon tetrachloride | 11.28 |
| Cellosolve acetate | |
| Chlorobenzene | 9.07 |
| Chlorobromomethane | |
| 1-Chloro-2-bromoethane | 10.63 |
| 1-Chlorobutane | 10.67 |
| 2-Chlorobutane | 10.65 |
| 1-Chlorobutanone | 9.54 |
| 1-Chloro-2,3 epoxy propane | 10.60 |
| Chloroethane (ethyl chloride) | 10.97 |
| Chlorethene | 10.00 |
| 2-Chloroethoxyethene | 10.61 |
| 1-Chloro-2-fluorobenzene | 9.16 |
| 1-Chloro-3-fluorobenzene | 9.21 |
| 1-Chloro-2-flouroethene (cis) | 9.87 |
| 1-Chloro-2-fluoroethene(trans) | 9.87 |
| Chloroform | 11.37 |

## Exhibit 15-2
## (continued)

| | eV |
|---|---|
| O-chloroiodobenzene | 8.35 |
| 1-Chloro-2-methylbenzene | 8.72 |
| 1 Chloro-3-methylbenzene | 8.61 |
| 1-Chloro-4-methylbenzene | 8.78 |
| Chloromethylethyl ether | 10.08 |
| Chloromethylmethyl ether | 10.25 |
| 1-chloro-2-methylpropane | 10.66 |
| Chloroprene | |
| 1-Chloropropane | 10.82 |
| 2-Chloropropane | 10.78 |
| 3-Chloropropene | 10.04 |
| P-chlorostyrene | |
| 2-Chlorothiophene | 8.68 |
| O-chlorotoluene | 8.83 |
| M-chlorotoluene | 8.83 |
| P-chlorotoluene | 8.70 |
| Cumene (i-propyl benzene) | 8.75 |
| Crotonaldehyde | 9.73 |
| Cyanoethene | 10.91 |
| Cyanogen bromide | 10.91 |
| 3-Cyanopropene | 10.39 |
| Cyclobutane | 10.50 |
| Cyclohexane | 9.98 |
| Cyclohexanone | 9.14 |
| Cyclohexene | 8.95 |
| Cyclo-octatetraene | 7.99 |
| Cyclopentadiene | 8.55 |
| Cyclopentane | 10.52 |
| Cyclopentanone | 9.26 |
| Cyclopentene | 9.01 |
| Cyclopropane | 10.06 |
| 2-Decanone | 9.40 |
| 1,3-Dibromobutane | |
| 1,4-Dibromobutane | |
| Dibromochloromethane | 10.59 |
| Dibromochloropropane | |
| 1,1-Dibromoethane | 10.19 |
| Dibromemethane | 10.49 |
| 1,2-Dibromopropane | 10.26 |
| 2,2-Dibromopropane | |
| 1,2-Dichlorobenzene | 9.07 |
| 1,3-Dichlorobenzene | 9.12 |
| 1,4-Dichlorobenzene | 8.94 |
| 1,3-Dichlorobutane | |
| 1,4-Dichlorobutane | |
| 1,4-Dichloro-2-butene (cis) | |
| 2,2-Dichlorobutane | |
| 2,3-Dichlorobutane | |
| 3,4-Dichlorobutene (Freon 12) | |

| | eV |
|---|---|
| Dichlorodifluoromethane | 11.75 |
| 1,1-Dichloroethane | 11.06 |
| 1,2-Dichloroethane | 11.04 |
| Cis-dichloroethene | 9.65 |
| Trans-dichloroethene | 9.66 |
| Dichloroethyl ether | |
| Dichloromethane | 11.35 |
| 1,2-Dichloropropane | 10.87 |
| 1,3-Dichloropropane | 10.85 |
| 1,1-Dichloropropanone | 9.71 |
| 2,3-Dichloropropene | 9.82 |
| Dicyclopentadiene | 7.74 |
| Dibutyl amine | 7.69 |
| Diethoxymethane | 9.70 |
| Diethyl amine | 8.01 |
| Diethyl ether | 9.53 |
| N-diethyl formamide | 8.89 |
| Diethyl ketone | 9.32 |
| Diethyl sulfide | 8.43 |
| 1,2-Difluorobenzene | 9.31 |
| 1,4-Difluorobenzene | 9.15 |
| Difluorodibromomethane | 11.18 |
| Difluoromethylbenzene | 9.45 |
| 1,1-Dimethoxyethane | 9.65 |
| Dimethoxymethane | 10.00 |
| Diiodomethane | 9.34 |
| Diisobutyl ketone | 9.04 |
| Diisopropylamine | 7.73 |
| Dimethyl amine | 8.24 |
| 2,3-Dimethylbutadiene | 8.72 |
| 2,2-Dimethyl butane | 10.06 |
| 2,2-Dimethyl butane-3-one | 9.18 |
| 2,3-Dimethyl butane | 10.02 |
| 2,3-Dimethyl-2-butene | 8.30 |
| 3,3-Dimethyl butanone | 9.17 |
| Dimethyl disulfide | 8.46 |
| Dimethyl ether | 10.00 |
| Dimethylformamide | 9.45 |
| 3,5-Dimethyl-4-heptanone | 9.04 |
| 2,2-Dimethyl-3-pentanone | 8.98 |
| 2,2-Dimethyl-propane | 10.35 |
| Dimethyl sulfide | 8.69 |
| Di-n-propyl disulfide | 8.27 |
| Di-n-propyl ether | 9.27 |
| Di-i-propyl ether | 9.20 |
| Di-n-propyl amine | 7.84 |
| Di-n-propyl sulfide | 8.30 |
| Epichlorohydrin | 10.60 |
| Ethane | 11.65 |
| Ethanal | 10.21 |

**Exhibit 15-2**
**(continued)**

| | eV |
|---|---|
| Ethanol | 10.62 |
| Ethanethiol (ethyl mercaptan) | 9.29 |
| Ethene (ethylene) | 10.52 |
| Ethyl acetate | 10.11 |
| Ethyl amine | 8.86 |
| Ethyl amyl ketone | 9.10 |
| Ethyl benzene | 8.76 |
| Ethyl bromide | 10.29 |
| Ethyl butyl ketone | 9.02 |
| Ethyl chloride (chloroethane) | 10.98 |
| Ethyl chloroacetate | 10.20 |
| Ethyl ethanoate | 10.10 |
| Ethyl disulfide | 8.27 |
| Ethylene chlorohydrin | 10.90 |
| Ethylene dibromide (EDB) | 10.37 |
| Ethylene glycol dinitrate | |
| Ethylene oxide | 10.56 |
| Ethyl formate | 10.61 |
| Ethyl iodide | 9.33 |
| Ethyl methanoate | 10.61 |
| Ethyl isothiocyanate | 9.14 |
| Ethyl methyl sulfide | 8.55 |
| Ethyl propanoate | 10.00 |
| Ethyl trichloroacetate | 10.44 |
| Ethylidene chloride | |
| Ethynylbenzene | 8.82 |
| | |
| Mono-fluorobenzene | 9.20 |
| Mono-fluoroethene | 10.37 |
| Mono-fluoromethanal | 11.4 |
| Fluorotribromomethane | 10.67 |
| O-fluorotoluene | 8.92 |
| M-fluorotoluene | 8.92 |
| P-fluorotoluene | 8.79 |
| Freon 11 ($CFCl_3$) | 11.77 |
| Freon 12 ($CF_2Cl_2$) | 12.91 |
| Freon 13 ($CF_3Cl$) | 12.91 |
| Freon 13 B-1$^3$ | 12.08 |
| Freon 14 (neat) | 16.25 |
| Freon 22 ($CHClF_2$) | 12.45 |
| Freon 113 ($CF_3CCl_3$) | 11.78 |
| 2-Furaldehyde | 9.21 |
| Furan | 8.89 |
| Furfuryl alcohol | |
| Furfural | 9.21 |
| | |
| Hexachloroethane | |
| N-hexane | 10.18 |
| N-heptane | 10.07 |
| 2-Heptanone | 9.33 |
| 4-Heptanone | 9.12 |
| 1-Hexene | 9.46 |

| | eV |
|---|---|
| Hexanone | |
| Hexamethylbenzene | 7.85 |
| Hydrazine | |
| Hydrogen cyanide | 13.91 |
| Hydrogen selenide | 9.88 |
| Hydrogen sulfide | 10.46 |
| Hydrogen telluride | 9.14 |
| | |
| Iodine | 9.28 |
| Iodobenzene | 8.73 |
| 1-Iodobutane | 9.21 |
| 2-Iodobutane | 9.09 |
| Iodoethane (ethyl iodide) | 9.33 |
| iodomethane (methyl iodide) | 9.54 |
| 1-Iodo-2-methylpropane | 9.18 |
| 1-Iodo-2-methylpropane | 9.02 |
| 1-Iodopentane | 9.19 |
| 1-Iodopropane | 9.26 |
| 2-Iodopropane | 9.17 |
| O-iodotoluene | 8.62 |
| M-iodotoluene | 8.61 |
| P-iodotoluene | 8.50 |
| Isoamyl acetate | 9.90 |
| Isoamyl alcohol | 10.16 |
| Isobutane | 10.57 |
| Isobutyl amine | 8.70 |
| Isobutyl acetate | 9.97 |
| Isobutyl alcohol | 10.47 |
| Isobutyl formate | 10.46 |
| Isobutyraldehyde | 9.74 |
| Isopentane | 10.32 |
| Isoprene | 8.85 |
| Isopropyl acetate | 9.99 |
| Isopropyl alcohol | 10.16 |
| Isopropyl amine | 8.72 |
| Isopropyl benzene | 8.75 |
| isopropyl ether | 9.20 |
| Isovaleraldehyde | 9.71 |
| | |
| Mesitylene | 8.40 |
| Mesityl oxide | 9.08 |
| Methanol | 10.85 |
| Methyl acetate | 10.27 |
| Methyl acrylate | 10.72 |
| Methyl amine | 8.97 |
| Methyl bromide | 10.53 |
| 2-Methyl-1,3-butadiene | 8.85 |
| 2-Methylbutanal | 9.71 |
| 2-Methylbutane | 10.31 |

**Exhibit 15-2**
**(continued)**

| | eV |
|---|---|
| 2-Methyl-1-butene | 9.12 |
| 3-Methyl-1-butene | 9.51 |
| 3-Methyl-2-butene | 8.67 |
| Methyl n-butyl ketone | 9.34 |
| Methyl butyrate | 10.07 |
| Methyl cellosolve | |
| Methyl chloroacetate | 10.35 |
| Methyl chloride | 11.28 |
| Methyl chloroform | 11.25 |
| Methylcyclohexane | 9.85 |
| 4-Methylcyclohexene | 8.91 |
| Methylcyclopropane | 9.52 |
| Methyl dichloroacetate | 10.44 |
| Methyl ethanoate | 10.27 |
| Methyl ethyl ketone | 9.53 |
| Methyl ethyl sulfide | 8.55 |
| 2-Methyl furan | 8.39 |
| Methyl Iodine | 9.54 |
| Methyl isobutyl ketone | 9.30 |
| Methyl Isobutyrate | 9.98 |
| 1-Methyl-4-isopropylbenzene | |
| Methyl isopropyl ketone | 9.32 |
| Methyl methacrylate | 9.74 |
| Methyl methanoate | 10.82 |
| Methyl mercaptan | 9.44 |
| 2-Methylpentane | 10.12 |
| 3-Methylpentane | 10.08 |
| 2-Methylpropane | 10.56 |
| 2-Methylpropanal | 9.74 |
| 2-Methyl-2-propanol | 9.70 |
| 2-Methylpropene | 9.23 |
| Methyl n-propyl ketone | 9.39 |
| Methyl styrene | 8.35 |
| Morpholine | 8.88 |
| Naphthalene | 8.10 |
| Nitric oxide | 9.25 |
| Nitrobenzene | 9.92 |
| Nitrotoluene | 9.43 |
| N-nonane | |
| 5-Nonanone | 9.10 |
| N-octane | |
| 3-Octanone | 9.19 |
| 4-Octanone | 9.10 |
| 1-Octene | 9.52 |

| | eV |
|---|---|
| N-pentane | 10.35 |
| Pentachloroethane | 11.28 |
| 1,3-Pentadiene (cis) | 8.59 |
| 1,3-Pentadiene (trans) | 8.56 |
| Pentafluorobenzene | 9.84 |
| Pentamethylbenzene | 7.92 |
| N-pentanal | 9.82 |
| 2,4-Pentanedione | 8.87 |
| 2-Pentanone | 9.39 |
| 3-Pentanone | 9.32 |
| 1-Pentene | 9.50 |
| Perchloroethylene | 9.32 |
| Perfluoro-2-butene | 11.25 |
| Perfluoro-1-heptene | 10.48 |
| N-perfluoropropyl iodide | 10.36 |
| (N-perfluoropropyl)-iodomethane | 9.96 |
| (N-perfluoropropyl)-methyl ketone | 10.58 |
| Phenol | 8.69 |
| Phenyl ether | 8.09 |
| Phenyl isocyanate | 8.77 |
| Phosphine | 9.96 |
| Pinene | 8.07 |
| Propadiene | 10.19 |
| N-propanal | 9.95 |
| Propane | 11.07 |
| 1-Propanethiol | 9.20 |
| N-propanol | 10.51 |
| Propanone | 9.69 |
| Propenal (acrolein) | 10.10 |
| Propene | 9.73 |
| Prop-1-ene-2-ol | 8.2 |
| Prop-2-ene-1-ol | 9.67 |
| Propionaldehyde | 9.98 |
| N-propyl acetate | 10.04 |
| N-propyl alcohol | 10.20 |
| N-propyl amine | 8.78 |
| N-propyl benzene | 8.72 |
| Propylene | 9.73 |
| Propylene dichloride | |
| Propylene oxide | 10.22 |
| N-propyl ether | 9.27 |
| N-propyl formate | 10.54 |
| Propyne | 10.36 |
| Pyridine | 9.32 |
| Styrene | 8.47 |

**Exhibit 15-2**
**(continued)**

| | eV |
|---|---|
| Tetrabromoethane | |
| Tetrachloroethene | 9.32 |
| 1,1,1,2-Tetrachloroethane | |
| 1,1,2,2-Tetrachloroethane | |
| 1,2,3,4-Tetrafluorobenzene | 9.61 |
| 1,2,3,5-Tetrafluorobenzene | 9.55 |
| 1,2,3,5-Tetrafluorobenzene | 9.39 |
| Tetrafluoroethene | 10.12 |
| Tetrahydrofuran | 9.54 |
| Tetrahydropyran | 9.26 |
| 1,2,4,5-Tetramethylbenzene | 8.03 |
| 2,2,4,4-Tetramethyl-3-pentanone | 8.65 |
| 1,1,1,2-Tetrachloropropane | |
| 1,2,2,3-Tetrachloropropane | |
| Thioethanol | 9.29 |
| Thiomethanol | 9.44 |
| Thiophene | 8.86 |
| 1-Thiopropanol | 9.20 |
| Toluene | 8.82 |
| Tribromoethene | 9.27 |
| 1,1,1-Trichlorobutanone | 9.54 |
| 1,1,1-Trichloroethane | 11.25 |
| 1,1,2-Trichloroethane | |
| Trichloroethene | 9.45 |
| Trichloromethyl ethyl ether | 10.08 |
| 1,1,2-Trichloropropane | |
| 1,2,3-Trichloropropane | |
| Triethylamine | 7.50 |
| 1,2,4-Trifluorobenzene | 9.37 |
| 1,3,5-Trifluorobenzene | 9.32 |
| Trifluoroethene | 10.14 |
| 1,1,1-Trifluoro-2-iodoethane | 10.10 |
| Trifluoroiodomethane | 10.40 |
| Trifluoromethylbenzene | 9.68 |
| Trifluoromethylcyclohexane | 10.46 |
| 1,1,1-Trifluoropropene | 10.9 |
| Trimethyl amine | 7.82 |
| 1,2,3-Trimethylbenzene | 8.48 |
| 1,2,4-Trimethylbenzene | 8.27 |
| 1,3,5-Trimethylbenzene | 8.39 |
| 2,2,4-Trimethyl pentane | 9.86 |
| 2,2,4-Trimethyl-3-pentanone | 8.82 |
| | |
| N-valeraldehyde | 9.82 |
| Vinyl acetate | 9.19 |
| Vinyl benzene (styrene) | 8.47 |
| Vinyl bromide | 9.80 |
| Vinyl chloride | 10.00 |
| 4-Vinylcyclohexene | 8.93 |
| Vinyl ethanoate | 9.19 |
| Vinyl fluoride | 10.37 |
| Vinyl methyl ether | 8.93 |
| | |
| O-xylene | 8.56 |
| M-xylene | 8.56 |
| P-xylene | 8.45 |

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Source: Photovac Technical Bulletin No. 11

* Many compounds with an ionization potential of 10.6 eV or less will also be detected by the Photovac TIP (Total Ionizables Present) Monitor.

### 15.1.6.2 Field Operation

1. Before any field analyses, use the following steps to determine that the instrument is operational. This should occur before the instrument is taken into the field.

2. Check that the lecture bottle carrier gas supply is adequate (charge supply is 1,800 psi and should last approximately 3 days).

3. Set the pressure regulator to zero (fully counter clockwise) and turn on the main valve of the lecture bottle.

4. Slowly turn the regulator control clockwise until air begins to escape from the quick disconnect connection. Allow the line to purge for a few seconds.

5. Plug the quick-disconnect fitting into the free CARRIER IN port. Shut off and disconnect the air supply in use (usually a laboratory supply). Adjust the lecture bottle regulator to approximately 40 pounds per square inch gauge (psig). Set the required flowrate by using a bubble tube.

6. With the instrument in the power-down mode, disconnect the AC power supply. Allow 15 minutes for the effect of the gas line switchover to subside. This lack of AC power automatically switches the instrument to battery power. The instrument is now completely self-contained and, together with a battery powered recorder, may be taken into the field. Check the battery charge on the Photovac.

7. The instrument is now ready to be run through the startup procedures as discussed in Subsection 15.1.6.1.

8. If there are significant changes in ambient temperature (greater than 10F) when the instrument is moved from place to place, the column will require time to stabilize thermally. At higher sensitivities, a nonthermally stabilized column will manifest itself as baseline drift.

9. DO NOT conduct analyses while batteries are charging because heat generated during battery recharge will affect column retention times and may cause baseline drift.

### 15.1.6.3 Shutdown Procedure

1. Turn the POWER SWITCH to OFF.

2. Reduce the carrier gas flow to 2 cc/min.

3. If the instrument is being returned from the field, be sure to store the instrument hooked up to a larger laboratory carrier-gas supply.

4. Maintain the battery as indicated in the manufacturer's manual.

5. Unplug the unit except when charging batteries.

### 15.1.6.4 Maintenance and Calibration Schedule*

| Function | Frequency |
|---|---|
| • Battery charge when instrument has been operating exclusively on WALL current with no use of battery | Every 3 months for 10 hours on LOW |
| • Battery charge when instrument has been operated off batteries | After each use, 1-1/2 hours of HIGH charge for every hour of use (**DO NOT OVERCHARGE**) |
| • Calibration (running standards) | With each use |
| • Septum change | After approximately 50 injection |
| • Column reconditioning | Every 3 months or after heavy use, or when installing a new column |

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* The maintenance and calibration functions must be documented

### 15.1.6.5 Calibration Procedure

1. Photovac Incorporated conducts an instrument calibration and includes the chromatogram as a component of that instrument's instruction manual. A check of the instrument's performance can be accomplished by duplicating the factory calibration check and comparing the results. Since the Photovac is not a direct read out instrument and instrument response can be checked by running standards and comparing retention times on different days, a calibration should be performed by running standards only. This should be done before, during, and after an analysis. The concentration and identity of the standards are left up to the user, but it is recommended that an aromatic (i.e., benzene) and a chlorinated hydrocarbon (i.e., trichloroethylene) be included. The calibration can be performed as follows:

- Prepare a standard for water or air analysis. Most standards run on the Photovac range from 0.5 to 1.0 ppm.
- Obtain a syringe and withdraw an aliquot of headspace gas that will result in peaks that are large enough to see and not so large that they do not fit on the chart paper. (**Note:** Water standards should be vigorously shaken for approximately 2 minutes before an aliquot is taken for injection.)
- Compare peaks of identical standard injections made before, during, and after analyses.
- If peak heights of the above injections change significantly, note the sensitivity lost or gained on the chart paper and include this information on the resulting report.

### 15.1.6.6 Column Maintenance

1. The standard Photovac 10A10 is equipped with two columns. Column #1 is a 1-foot long, 1/8-inch outside diameter (OD) Teflon tube packed with CSP-20M. Column #2 is a 4-foot long, 1/8-inch OD Teflon tube packed with 5 percent SE-30 on 60-80 mesh Chromosorb G. Column

#1 is suitable for running blanks and other quick scans but will not achieve significant separation. Column #2 is suitable for running field surveys and analyses requiring detailed separations.

2. New columns must be conditioned overnight with ultra-high purity helium (FR) or nitrogen at a temperature of 100°C at a maximum flowrate of 100 cc/min. Reconditioning of older columns is accomplished under the same conditions.

3. To gain access to the columns, use the following procedure:

a. Disconnect the AC cord.

b. Disconnect the chart recorder lead.

c. Disconnect the lecture bottle carrier gas supply.

d. Remove the four Phillips screws securing the panel to the case, and remove the screw attaching the lid retainer to the lid. (Never remove the panel while the instrument is connected to the main power supply.)

e. Grasp the panel assembly by the cylinder clamp. Gently lift the rear of the panel clear of the case rim, and ease the panel assembly backward from the front rim. Lift the panel assembly clear.

f. Gently unplug the circuit board from the wire harness connection. Remove the nine Phillips screws from the gold box, and lift clear the lid / circuit board subassembly. The interior of the column/ ion cell chamber is now accessible.

g. To remove the column, locate the two fittings at each end of the column (ion cell body and injection part). Using a 5/6 inch open-ended wrench, loosen these fittings. Unscrew the fitting with the finger and remove the column.

h. To replace the column, reverse the previous steps and take special care not to damage the thread on the fitting. Make the fittings finger tight, and use the 5/16-inch open-ended wrench to give an additional 1/8 turn to assure that the fittings seat.

### 15.1.6.7 Septum Change

The 10A10 contains a Teflon-faced, silicone-rubber, 0.25-inch diameter septum. Hamilton "Micro Sep" F-138 is suitable. The septum can easily be replaced as follows:

1. Unscrew the septum retainer.

2. Extract the old septum with a fine pair of tweezers.

3. Insert the new septum with the Teflon face down.

4. Carefully screw the retainer back into place firmly, but without overtightening.

5. A 10- to 20-minute stabilization period may be required because the carrier gas flow is temporarily interrupted when the septum is changed.

#### 15.1.6.8 Troubleshooting

A list of common troubleshooting techniques for the Photovac 10A10 is provided in Exhibit 15-3.

### 15.1.7 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 15.1.8 Information Sources

Horgan, L. Proposed Guidelines for Photovac 10A10 for the Surveillance and Analysis Division. U.S. Environmental Protection Agency. 1983.

Photovac Incorporated. *Photovac 10A10 Operating Manual.*

## 15.2 HNU PI-101

### 15.2.1 Purpose

Subsection 15.2 discusses the use, maintenance, and calibration of the HNU PI-101.

### 15.2.2 Definitions

None.

### 15.2.3 Theory and Limitations

#### 15.2.3.1 Theory

The HNU is a portable, nonspecific, vapor / gas detector employing the principle of photoionization to detect a variety of chemical compounds, both organic and inorganic.

The HNU contains an ultraviolet (UV) light source within its sensor chamber. Ambient air is drawn into the chamber with the aid of a small fan. If the ionization potential (IP) of any molecule present in the ambient air is equal to or lower than the energy of the UV light source, ionization will take place, causing a deflection in the meter. Response time is approximately 90 percent at 3 seconds. The meter reading is expressed in parts per million (ppm). All readings must be stated as equivalent readings that depend on the calibration gas being used. For example, the standard gas used to calibrate the HNU is benzene, which allows the instrument to provide results in benzene equivalence. Exhibit 15-4, modified from the "*Instruction*

### Exhibit 15-3
### TROUBLESHOOTING PROCEDURES
### FIELD EQUIPMENT: PHOTOVAC 10A10

| Problem | Probable Cause | Remedy |
|---|---|---|
| 1. No chromatographic response | There is no carrier gas flow. | Check at OUT port with flow gauge. |
| | Batteries are flat (if on battery operation). | Plug into AC and check again. |
| | Electrometer is saturated. | Turn ATTENUATION to 10, set meter to 0. If OFFSET reads 10 or more, the instrument is saturated.<br>Allow to self-purge until clear. |
| | Syringe is plugged. | Try a new syringe. |
| | UV source is not on. | Check SOURCE ON light; if it is on, see item 9 in this exhibit. |
| 2. Unacceptable baseline drift | Unit has been subjected to large temperature change. | Allow to stabilize. |
| | A very concentrated sample has recently been introduced, resulting in excessive tailing. | Allow to self-purge until clear. |
| Unacceptable baseline drift | Unacceptable contamination levels are in carrier gas supply. | Change carrier gas supply, and allow instrument to stabilize. |
| | The unit is charging, and the resulting heat is affecting the column. | Turn CHARGE switch to OFF. |

**Exhibit 15-3**
**(continued)**

| Problem | Probable Cause | Remedy |
|---|---|---|
| 3. Deterioration of sensitivity | Syringe has leaky plunger. | Try a new syringe. |
| | Column needs conditioning. | Condition column. |
| | Septum is leaking. | Change septum. |
| | Column fittings leak. | Disassemble and check for leaks around fittings, while under pressure, with soap solution. |
| 4. Unacceptable low frequency noise | Column needs conditioning. | Condition column. |
| 5. Peaks elute very slowly | Carrier flowrate is too slow. | Adjust flowrate. |
| 6. Peaks eluting too fast | Carrier flowrate is too high. | Adjust flowrate. |
| 7. Peak has flat top | Electrometer has saturated. | Dilute sample and repeat. |
| 8. Peak is misshapen, with considerable tailing | Flow is too slow. | Adjust flow. |
| Peak is misshapen, with considerable tailing | There is an improper injection technique. | Repeat. |
| | Compound is wrongly matched to column; perhaps too polar. | Select appropriate column. |
| | Peak is developing from an earlier injection (overlap of peaks). | Allow greater time between injections, or install shorter column. |

**Exhibit 15-3**
**(continued)**

| Problem | Probable Cause | Remedy |
|---|---|---|
| Source OFF light stays on after 5 min. | Batteries are low (if battery operation). | Plug in AC connector. |
| | Tube driver is mismatched. | Contact Photovac for advice (416/881-8225). |
| 9. Electrometer does not return to zero after startup | Electrometer is saturated. | Allow to self-purge. |

If problems persist after trying all suggested remedies, contact Photovac Incorporated for advice.

Photovac Inc.
Unit 2
134 Doncaster Avenue
Thornhill, Ontario, Canada L3T 1L3
416/881-8225 Telex: 066-964634

*Manual for Model PI-101 Photoionization Analyzer*" HNU Systems Inc., 1975, lists the relative sensitivities for various gases.

#### 15.2.3.2 Limitations

1. If the IP of a chemical contaminant is greater than the UV light source, this chemical will not be recorded. Some contaminants cannot be determined by any sensor / probes.

2. It should be noted, specifically, that the HNU will not detect methane.

3. During cold weather, condensation may form on the UV light source window, resulting in erroneous results.

4. Instrument readings can be affected by humidity and powerlines, making it difficult to interpret readings.

5. Total concentrations are relative to the calibration gas (usually benzene) used.Therefore, true contaminants and their quantities cannot be identified. Also, while the instrument scale reads 0 to 2,000 ppm, response is linear (to benzene) from 0 to about 600 ppm. Greater concentrations may be "read" at a higher or lower level than the true value.

6. Wind speeds of greater than 3 miles an hour may affect fan speed and readings, depending on the position of the probe relative to wind direction.

### 15.2.4 Applicability

This procedure is applicable to HNU PI-101 instruments used for air monitoring.

### 15.2.5 Responsibilities

The SM is responsible for monitoring the implementation of these procedures.

### 15.2.6 Records

Training records, maintenance records, and calibration records will be generated and maintained by the responsible organization. The maintenance, calibration, and results obtained in the field will be recorded in the site logbook.

### 15.2.7 Procedure

#### 15.2.7.1 Maintenance and Calibration Responsibilities

The instrument user is responsible for properly calibrating and operating the instrument. When the instrument is scheduled for or requires maintenance, these functions should be conducted only by qualified individuals. If possible, maintenance responsibilities should be restricted to one or two individuals who will also bear responsibilities for logging the equipment in and out. Documentation of instrument user, dates of

## Exhibit 15-4
## RELATIVE SENSITIVITIES FOR VARIOUS GASES
## (10.2 eV Lamp)

| Species | Photoionization Sensitivity* |
|---|---|
| P-xylene | 11.4 |
| M-xylene | 11.2 |
| Benzene | 10.0 (reference standard) |
| Toluene | 10.0 |
| Diethyl sulfide | 10.0 |
| Diethyl amine | 9.9 |
| Styrene | 9.7 |
| Trichloroethylene | 8.9 |
| Carbon disulfide | 7.1 |
| Isobutylene | 7.0 |
| Acetone | 6.3 |
| Tetrahydrofuran | 6.0 |
| Methyl ethyl ketone | 5.7 |
| Methyl isobutyl ketone | 5.7 |
| Cyclohexanone | 5.1 |
| Naptha (86% aromatics) | 5.0 |
| Vinyl chloride | 5.0 |
| Methyl isocyanate | 4.5 |
| Iodine | 4.5 |
| Methyl mercaptan | 4.3 |
| Dimethyl sulfide | 4.3 |
| Allyl alcohol | 4.2 |
| Propylene | 4.0 |
| Mineral spirits | 4.0 |
| 2,3-Dichloropropene | 4.0 |
| Cyclohexene | 3.4 |
| Crotonaldehyde | 3.1 |
| Acrolein | 3.1 |
| Pyridine | 3.0 |
| Hydrogen sulfide | 2.8 |
| Ethylene dibromide | 2.7 |
| N-octane | 2.5 |
| Acetaldehyde Oxime | 2.3 |

## Exhibit 15-4
(continued)

| Species | Photoioniztion Sensitivity* |
|---|---|
| Hexane | 2.2 |
| Phosphine | 2.0 |
| Heptane | 1.7 |
| Allyl chloride (3-chloropropene) | 1.5 |
| Ethylene | 1.0 |
| Ethylene oxide | 1.0 |
| Acetic anhydride | 1.0 |
| Alpha pinene | 0.7 |
| Dibromochloropropane | 0.7 |
| Epichlorohydrin | 0.7 |
| Nitric oxide | 0.6 |
| Beta pinene | 0.5 |
| Citral | 0.5 |
| Ammonia | 0.3 |
| Acetic Acid | 0.1 |
| Nitrogen dioxide | 0.02 |
| Methane | 0.0 |
| Acetylene | 0.0 |
| Ethylene | 0.0 |

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*Expressed in ppm (v/v).

Source: *Instruction Manual for Model PI-101 Photoionization Analyzer,* HNU Systems, Inc., 1975.

use, instrument identification number, maintenance and calibration functions, and project identification should be maintained.

### 15.2.7.2 Operator Qualifications

The HNU, although a relatively simple instrument to use, can be incorrectly operated if the user is not thoroughly familiar with its operation. An appropriate training and certification procedure must be developed and incorporated into the responsible organization's training procedures. The users must complete the training and be certified for HNU operation before using the instrument in the field. Refresher courses should be obligatory every 6 months. Courses are given by the manufacturer, by commercial entities, and by EPA at their Cincinnati, Ohio, and Edison, New Jersey, facilities.

### 15.2.7.3 Startup / Shutdown Procedures

Startup

1. Check the FUNCTION switch on the control panel to make sure it is in the OFF position. Attach the probe to the readout unit. Match the alignment key, and twist the connector clockwise until a distinct locking is felt.

2. Turn the FUNCTION switch to the BATTERY CHECK position. Check that the indicator reads within or beyond the green battery arc on the scale plate. If the indicator is below the green arc, or if the red LED comes on, the battery must be charged before using.

3. To zero the instrument, turn the FUNCTION switch to the STANDBY position and rotate the ZERO POTENTIOMETER until the meter reads zero. Wait 15 to 20 seconds to confirm that the zero adjustment is stable. If it is not, then readjust.

4. Check to see that the SPAN POTENTIOMETER is set at the appropriate setting for the probe being used (5.0 for 9.5 eV probe, 9.8 for 10.2 eV, and 5.0 for 11.7 eV).

5. Set the FUNCTION switch to the desired ppm range. A violet glow from the UV lamp source should be observable at the sample inlet of the probe / sensor unit. (Do not look directly at the glow, since eye damage could result.)

6. Listen for the fan operation to verify fan function.

7. Check instrument with an organic point source, such as a "magic marker," before survey to verify instrument function.

Shutdown

1. Turn FUNCTION switch to OFF.

2. Disconnect the probe connector.

3. Place the instrument on the charger

### 15.2.7.4 Maintenance and Calibration Schedule

| Function | Frequency |
|---|---|
| • Perform routine calibration | Prior to each use* |
| • Initiate factory checkout and calibration | Yearly or when malfunctioning or after changing UV light source |
| • Wipe down readout unit | After each use |
| • Clean UV light source window | Every month or as use and site conditions dictate |
| • Clean the ionization chamber | Monthly |
| • Recharge battery | After each use |

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* During extended field use, the HNU PI-101 must be calibrated at least once every three days.

### 15.2.7.5 Calibration Procedure No. 1

For HNU calibration canisters without regulators:

1. Run through startup procedures as in Subsection 15.2.7.3.

2. Fill a sampling bag with HNU calibration gas of known contents.

3. Connect HNU probe to sampling bag by using flexible tubing.

4. Allow sample bag contents to be drawn into the probe, and check response in ppm.

5. Adjust the span potentiometer to produce the concentration listed on the span gas cylinder.This procedure shall be followed only until the span potentiometer reaches the following limits:

| Probe | Initial Span Pot. Setting | Maximum Acceptance Span Pot Setting |
|---|---|---|
| 9.5 eV | 5.0 | 1.0 |
| 10.2 eV | 9.8 | 8.5 |
| 11.7 eV | 5.0 | 2.0 |

6. If these limits are exceeded, the instruments must be returned for maintenance and recalibration. This maintenance will be done only by qualified individuals.

7. Each responsible organization must develop a mechanism for the documentation of calibration results. This documentation includes the following:

a. Date inspected

b. Person who calibrated the instrument

c. The instrument number (Serial number or other ID number)

d. The results of the calibration (ppm, probe eV, span potentiometer setting)

e. Identification of the calibration gas (source, type, concentration)

### 15.2.7.6 Calibration Procedure No. 2

For HNU calibration canisters equipped with a regulator:

1. Run through startup procedures as described in Subsection 15.2.6.3.

2. Connect a sampling hose to the regulator outlet and the other end to the sampling probe of the HNU.

3. Crack the regulator valve.

4. Take a reading after 5 to 10 seconds.

5. Adjust span potentiometer using the steps outlined in step No. 5 of Subsection 15.2.7.5.

6. Calibration documentation should be as in step No. 7 in Subsection 15.2.7.5.

### 15.2.7.7 Cleaning the UV Light-Source Window

1. Turn the FUNCTION switch to the OFF position, and disconnect the sensor / probe from the Readout / Control unit.

2. Remove the exhaust screw located near the base of the probe. Grasp the end cap in one hand and the probe shell in the other. Separate the end cap and lamp housing from the shell.

3. Loosen the screws on the top of the end cap, and separate the end cap and ion chamber from the lamp and lamp housing, taking care that the lamp does not fall out of the lamp housing.

4. Tilt the lamp housing with one hand over the opening so that the lamp slides out of the housing into your hand.

5. The lamp window may now be cleaned using lens paper with any of the following compounds:

   a. Use HNU Cleaning Compound on all lamps except the 11.7 eV.

b. Clean the 11.7 eV lamp with a freon or chlorinated organic solvent. Do not use HNU cleaner, water, or water miscible solvents (i.e., acetone and methanol).

6. Following cleaning, reassemble by first sliding the lamp back into the lamp housing. Place the ion chamber on top of the housing, making sure the contacts are properly aligned.

7. Place the end cap on top of the ion chamber, and replace the two screws. Tighten the screws only enough to seal the O-ring. Do not overtighten.

8. Line up the pins on the base of the lamp housing with pins inside the probe shell, and slide the housing assembly into the shell.It will fit only one way.

9. Replace the exhaust screw.

### 15.2.7.8 Cleaning the Ionization Chamber

1. Turn the FUNCTION switch to the OFF position, and disconnect the sensor/probe from the Readout / Control unit.

2. Remove the exhaust screws located near the base of the probes. Grasp the end cap in one hand and the probe shell in the other. Separate the end cap and lamp housing from the shell.

3. Loosen the screws on the top of the end cap, and separate the end cap and ion chamber from the lamp and lamp housing, taking care that the lamp does not fall out of the lamp housing.

4. The ion chamber may now be cleaned according to the following sequence:

   a. Clean with methanol using a Q-tip.

   b. Dry gently at 50°C to 60°C for 1/2 hour.

5. Place the ion chamber on top of the housing, making sure the contacts are properly aligned.

6. Place the end cap on top of the ion chamber and replace the two screws. Tighten the screws only enough to seal the O-ring. Do not overtighten.

7. Line up the pins on the base of the lamp housing with pins inside the probe shell, and slide the housing assembly into the shell. It will fit only one way.

### 15.2.7.9 Troubleshooting

The following steps should be performed only by a qualified technician:

1. The meter does not respond in any switch position (including BATT CHK).

   a. Meter movement is broken.

(1) Tip instrument rapidly from side to side. Meter needle should move freely and return to zero.

b. Electrical connection to meter is broken

(1) Check all wires leading to meter.

(2) Clean the contacts of quick-disconnects.

c. Battery is completely dead.

(1) Disconnect battery.

(2) Check voltage with a volt-ohm meter.

d. Check 2 mp fuse.

e. If none of the above solves the problem, consult the factory.

2. Meter responds in BATT CHK position, but reads zero or near zero for all others.

a. Power supply is defective.

(1)Check power supply voltages as shown in Figure 11 of the HNU *Instruction Manual*. If any voltage is out of specification, consult the factory.

b. Input transistor or amplifier has failed.

(1) Rotate zero control; meter should deflect up or down as control is turned.

(2) Open probe. Both transistors should be fully seated in sockets.

c. Input signal connection is broken in probe or readout.

(1) Check input connector on printed circuit board. The input connector should be firmly pressed down.

(2) Check components on back of printed circuit board. All connections should be solid, and no wires should touch any other object.

(3) Check all wires in readout for solid connections.

3. Instrument responds correctly in BATT CHK and STBY but not in measuring mode.

a. Check to see that the light source is on. Do not look directly at UV light source, since eye damage could result.

(1) Check high-voltage power supply.

(2) Open end of probe, remove lamp, and check high voltage on lamp ring.

(3) If high voltage is present at all above points, light source has probably failed. Consult the factory.

4. Instrument responds correctly in all positions, but signal is lower than expected.

    a. Check span setting for correct value.

    b. Clean window of light source.

    c. Double check preparation of standards.

    d. Check power supply 180 V output.

    e. Check for proper fan operation. Check fan voltage.

    f. Rotate span setting. Response should change if span potentiometer is working properly.

5. Instrument responds in all switch positions, but is noisy (erratic meter movement).

    a. Open circuit in feedback circuit.Consult the factory.

    b. Open circuit in cable shield or probe shield. Consult the factory.

6. Instrument response is slow and/or irreproducible.

    a. Fan is operating improperly. Check fan voltage.

    b. Check calibration and operation.

7. The battery indicator is low.

    a. Indicator comes on if battery charge is low.

    b. Indicator also comes on if ionization voltage is too high.

### 15.2.8 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 15.2.9 Information Sources

HNU Systems, Inc.*Instruction Manual for Model PI-101 Photoionization Analyzer*. 1975.

Ecology and Environment.*FIT Operation and Field Manual: HNU Systems PI-101 Photoionization Detector and Century Systems (Foxboro) Model OVA-128 Organic Vapor Analyzer*. 1981.

Personal Communication with Fran Connel, HNU Systems, Inc. 4 January 1984.

CH2M HILL. *Field Surveillance Equipment.* 1984.

Rabin, Linda J."Selective Application of Direct-Reading Instruments at Hazardous Waste Sites," presented at American Industrial Hygiene Conference, Dallas, Texas. 1986.

## 15.3 ORGANIC VAPOR ANALYZER (OVA-128)

### 15.3.1 Scope and Purpose

The purpose of this subsection is to discuss the use, maintenance, and calibration of the OVA-128.

### 15.3.2 Definitions

None.

### 15.3.3 Theory and Limitations

#### 15.3.3.1 Theory

The OVA uses the principle of hydrogen flame ionization for the detection and measurement of organic compounds. The OVA contains a diffusion flame of hydrogen and air that is free of ions and is nonconducting. When a sample of organic material is introduced into the flame, ions are formed, causing the flame to become conductive. Eventually this conductivity provides a meter reading because of a change in current.

#### 15.3.3.2 Limitations

1. The OVA will not see any inorganics.

2. The OVA will "see" methane, which is explosive but relatively nontoxic. The user should determine if the contaminant involved is or is not methane.

3. DOT shipping regulations are strict for the OVA when shipped containing pressurized hydrogen.

4. A relative humidity greater than 95 percent will cause inaccurate and unstable responses.

5. A temperature less than 40°F will cause slow and poor response.

6. Actual contaminant concentrations are measured relative to the calibration gas used. Therefore, specific contaminants and their quantities cannot easily be identified.

7. As with the HNU Photoionizer, the OVA responds differently to different compounds. The table below is a list, provided by the manufacturer, of the relative sensitivities of the OVA to some common organic compounds. Since the instrument is factory calibrated to methane, all relative responses are given in percent, with methane at 100.

| Compound | Relative Response |
|---|---|
| Methane | 100 |
| Ethane | 90 |
| Propane | 64 |
| N-butane | 61 |
| N-pentane | 100 |
| Ethylene | 85 |
| Acetylene | 200 |
| Benzene | 150 |
| Toluene | 120 |
| Acetone | 100 |
| Methyl ethyl ketone | 80 |
| Methyl isobutyl ketone | 100 |
| Methanol | 15 |
| Ethanol | 25 |
| Isoproply alcohol | 65 |
| Carbon tetrachloride | 10 |
| Chloroform | 70 |
| Trichloroethylene | 72 |
| Vinyl chloride | 35 |

8. When operated in the gas chromatography (GC) mode, chemical standards of known constituents and concentration must be analyzed by the GC. These standards must be run at the same operating conditions used in the sampling procedure, i.e., carrier gas flowrate, column type and temperature, and ambient conditions. The purpose of running standards is to determine retention times, concentrations (or instrument response), and optimal instrument operating conditions.

### 15.3.4 Applicability

This procedure is applicable to all OVA-128s used for field or laboratory applications.

### 15.3.5 Responsibilities

The SM is responsible for monitoring the implementation of these procedures.

### 15.3.6 Records

Training records, maintenance records, and calibration records will be generated and maintained by the responsible organization. The maintenance, calibration, and results obtained in the field will be recorded in the site logbook.

### 15.3.7 Procedure

#### 15.3.7.1 Maintenance and Calibration Responsibilities

It is preferable to minimize the number of people responsible for maintenance and calibration of the OVA. These people should also be responsible for logging the equipment in and out. Documentation of instrument user, dates of use, instrument identification number, maintenance and calibration procedures, and project identification should be maintained.

#### 15.3.7.2 Operator Qualifications

Although it is a relatively simple instrument to use, the OVA can be incorrectly operated if the user is not thoroughly familiar with its operation. An appropriate training and certification procedure must be developed and incorporated into the responsible organization's training procedures. The user must complete the training and be certified for OVA use before taking the instrument into the field. Refresher courses should be obligatory every 6 months. Courses are offered by the manufacturer, various commercial entities, and by EPA at their Cincinnati, Ohio, and Edison, New Jersey, facilities.

#### 15.3.7.3 Startup Procedures

1. Connect the probe / readout connectors to the side-pack assembly.

2. Check battery condition and hydrogen supply.

3. For measurements taken as methane equivalent, check that the GAS SELECT dial is set at 300.

4. Turn the electronics on by moving the INST switch to the ON position, and allow 5 minutes for warm-up.

5. Set CALIBRATE switch to X10; use CALIBRATE knob to set indicator at 0.

6. Open the $H_2$ tank valve all the way and the $H_2$ supply valve all the way. Check that the hydrogen supply gauge reads between 8.0 and 12.0 psig.

7. Turn the PUMP switch ON, and check the flow system according to the procedures in Subsection 15.3.7.6.

8. Check that the BACKFLUSH and INJECT valves are in the UP position.

9. To light the flame, depress the igniter switch until a meter deflection is observed.The igniter switch may be depressed for up to 5 seconds. Do not depress for longer than 5 seconds, as it may burn out the igniter coil. If the instrument does not light, allow the instrument to run several minutes and repeat ignition attempt.

10. Confirm OVA operational state by using an organic source, such as a "magic marker."

11. Establish a background level in a clean area or by using the charcoal scrubber attachment to the probe (depress the sample inject valve) and by recording measurements referenced to background.

12. Set the alarm level, if desired.

### 15.3.7.4 Shutdown Procedure

1. Close $H_2$ supply valve and $H_2$ tank valve (do not overtighten valves).

2. Turn INST switch to OFF.

3. Wait until $H_2$ supply gauge indicates system is purged of $H_2$; then switch off pump (approximately 10 seconds).

4. Put instrument on electrical charger at completion of day's activities.

### 15.3.7.5 Maintenance and Calibration Schedule

| | |
|---|---|
| Check particle filters | Weekly or as needed |
| Check quad rings | Monthly or as needed |
| Clean burner chamber | Monthly or as needed |
| Check secondary calibration | Prior to project startup |
| Check primary calibration | Monthly, or if secondary check is off by more than ± 10 percent |
| Check pumping system | Before project startup |
| Replace charcoal in scrubber attachment | 120 hours of use, or when background readings are higher with the inject valve down than with the inject valve up in a clean environment |
| Factory service | At least annually |

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Note: Instruments that are not in service for extended periods of time need not meet the above schedule. However, they must be given a complete checkout before their first use, addressing the maintenance items listed above.

## Calibration Procedures

The following steps are to be used only by qualified service technicians:

### Primary Calibration

1. Remove instrument components from the instrument shell.
2. Turn on ELECTRONICS and ZERO INSTRUMENT on X10 scale. Gas select dial to 300.
3. Turn on PUMP and HYDROGEN. Ignite flame. Go to SURVEY MODE.
4. Introduce a methane standard near 100 parts per million (ppm).
5. Adjust R-32 Trimpot on circuit board to make meter read to standard.
6. Turn off hydrogen flame, and adjust meter needle to read 40 ppm (calibrate @ X10) using the calibration adjust knob.
7. Switch to X100 scale. The meter should indicate 0.4 on the 1-10 meter markings (0.4 x 100 = 40 ppm). If the reading is off, adjust with R33 Trimpot.
8. Return to X10 scale, and adjust meter needle to 40 ppm with calibration; adjust knob, if necessary.
9. At the X10 scale, adjust meter to read 0.4 on the 1 to 10 meter markings using the calibration adjust. Switch to X1 scale. The meter should read 4 ppm. If the reading is off, adjust using the R31 Trimpot.

### Secondary Calibration

1. Fill an air sampling bag with 100 ppm (certified) methane calibration gas.
2. Connect the outlet of the air-sampling bag to the air-sampling line of the OVA.
3. Record the reading obtained from the meter on the calibration record.

### Documentation

Each responsible organization should develop a system whereby the following calibration information is recorded:

- 1. Instrument calibrated (I.D. or serial number)
- 2. Date of calibration
- 3. Method of calibration

- 4. Results of the calibration
- 5. Identification of person who calibrated the instrument
- 6. Identification of the calibration gas (source, type, concentration, lot number)

### 15.3.7.6 Pump System Checkout

The following steps are to be used only by qualified technicians:

1. With the pump on, hold unit upright and observe flow gauge.
2. See if ball level is significantly below a reading of 2; if so, flow is inadequate.
3. Check connections at the sample hose.
4. Clean or replace particle filters if flow is impaired or if it is time for scheduled service.
5. Reassemble and retest flow.
6. If flow is still inadequate, replace pump diaphragm and valves.
7. If flow is normal, plug air intake.Pump should slow and stop.
8. If there is no noticeable change in pump, tighten fittings and retest.
9. If there is still no change, replace pump diaphragm and valves.
10. Document this function in the maintenance records.

### 15.3.7.7 Burner Chamber Cleaning

1. Remove plastic exhaust port cover.
2. Unscrew exhaust port.
3. Use wire brush to clean burner tip and electrode.Use wood stick to clean Teflon.
4. Brush inside of exhaust port.
5. Blow out chamber with a gentle air flow.
6. Reassemble and test unit.
7. Document this function in the maintenance records.

### 15.3.7.8 Quad Ring Service

1. Remove OVA instruments from protective shell.
2. Remove clip ring from bottom of valve.
3. Unscrew nut from top of valve.
4. Gently pull valve shaft upward and free of housing.
5. Observe rings for signs of damage; replace as necessary.
6. Lightly grease rings with silicone grease.
7. Reassemble valve; do not pinch rings during shaft insertion.
8. Document this function in the maintenance records.

### 15.3.7.9 Troubleshooting

| Indication | Possible Causes |
|---|---|
| • High background reading (More than 10 ppm) | Contaminated hydrogen<br>Contaminated sample line |
| • Continual flameout | Hydrogen leak<br>Dirty burner chamber<br>Dirty air filter |
| • Low air flow | Dirty air filter<br>Pump malfunction<br>Line obstruction |
| • Flame will not light | Low battery<br>Igniter broken<br>Hydrogen leak<br>Dirty burner chamber<br>Air flow restricted |
| • No power to pump | Low battery<br>Short circuit |
| • Hydrogen leak (Instrument not in use) | Leak in regulator<br>Leak in valves |

### 15.3.7.10 Hydrogen Recharging

1. High-grade hydrogen (99.999 percent) is required. Maximum pressure the instrument can handle is 2,300 psig.

2. Connect the fill hose to the REFILL FITTING on the side pack assembly with the FILL/BLEED valve in the OFF position.

3. Open $H_2$ SUPPLY BOTTLE valve.

4. Place FILL/BLEED valve on fill hose in BLEED position momentarily to purge any air out of the system.

5. Open the instrument TANK valve.

6. Open REFILL valve on instrument.

7. Place FILL/BLEED valve in FILL position until the instrument pressur[illegible]uge equalizes with the $H_2$ SUPPLY BOTTLE pressure gauge.

8. Shut REFILL valve, FILL/BLEED valve, and $H_2$ SUPPLY BOTTLE valve, in quick succession.

9. Turn FILL/BLEED valve to BLEED until hose pressure equalizes to atmospheric pressure.

10. Turn FILL/BLEED valve to FILL position; then turn the valve to the BLEED position; then turn to OFF.

11. Close TANK on instrument.

12. Disconnect the FILL HOSE, and replace protective nut on the REFILL FITTING.

### 15.3.7.11 Particle Filter Servicing

Filters have been placed at two points in the air sampling line of the OVA to keep particulates from entering the instrument. The first filter is located in the probe assembly, and the second filter (primary filter) is located on the side pack assembly. Cleaning procedures are as follows:

1. Detach the probe assembly from the readout assembly.

2. Disassemble the probe (unscrew the components).

3. Clean the particle filter located within the probe by blowing air through the filter.

4. Reassemble the probe.

5. Gain access to the primary filter, located behind the sample inlet connector on the side pack assembly, by removing the sample inlet connector with a thin-walled, 7/16-inch socket wrench. Remove the filter, and clean as above.

6. Reassemble the sample inlet fitting and filter to the side pack assembly.

7. Check sample flowrate.

#### 15.3.7.12 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

#### 15.3.7.13 Information Sources

The following references were used in generating this subsection of the compendium:

Region II FIT. *Proposed Guidelines for the Organic Vapor Analyzer.* 1984.

Ecology and Environment. *FIT Operation and Field Manual: HNU Systems PI-101 Photoionization Detector and Century Systems (Foxboro) Model OVA-128 Organic Vapor Analyzer.* 1981.

Century Systems (Foxboro). *Service Procedures: Organic Vapor Analyzer*, 128GC.

CH2M HILL. *Field Surveillance Equipment.* 1984.

## 15.4 EXPLOSIMETER

### 15.4.1 Scope and Purpose

This subsection provides general guidance for the understanding, use, and application of an explosimeter. The methodologies refer to explosimeters manufactured by Mine Safety Appliances Company.

### 15.4.2 Definitions

**Explosimeter**
An instrument used to test an atmosphere for concentration of combustible gases and vapors.

**Lower Explosive Limit (LEL)**
The lowest concentration of a gas or vapor in air, by volume, that will explode or burn when there is an ignition source present.

**Upper Explosive Limit (UEL)**
The maximum concentration of a gas or vapor in air, by volume, that will explode or burn when there is an ignition source present.

## 15.4.3 Applicability

Explosimeters have been used during installation of monitoring wells and in and around landfills where methane gas is of primary concern. Once a monitoring well is installed, methane gas can accumulate inside the well casing and can create a potentially explosive environment.

Explosimeters have also proved useful during the excavation of buried drums and tanks. In what can sometimes seem like an innocuous situation because of the adequate ventilation around the trench, heavier-than-air vapors can collect at the bottom of the trench to produce an explosive environment. Additionally, the explosimeter has provided service when investigative work has discovered abandoned warehouses and storage sheds containing drums of volatile substances. The explosimeter is typically used when entering any confined space or for initial entry on hazardous waste sites.

## 15.4.4 Responsibilities

Before the instrument is taken into the field, it should be inspected and calibrated to ensure that it is operating properly. If possible, maintenance and calibration should be restricted to one or two qualified individuals.

## 15.4.5 Records

Logbooks should contain records of the instrument checkout and calibration procedures. Although a relatively simple instrument to use, the explosimeter can be incorrectly operated if the user is not thoroughly familiar with its operation. An appropriate training and certification procedure must be developed and incorporated. The users must complete the training and be certified for operation before using the explosimeter in the field. Refresher courses should be obligatory every 6 months. Courses are offered by the manufacturer, various commercial entities, and by EPA at their Cincinnati, Ohio, and Edison, New Jersey, facilities.

## 15.4.6 Procedures

### 15.4.6.1 Theory

A typical explosimeter draws a sample of the atmosphere over a heated catalytic filament that forms a balanced electrical circuit. Combustibles that are present in the atmosphere are burned on the filament, which raises its resistance in proportion to the concentration of the combustibles in the atmosphere. The resulting imbalance of the circuit causes a deflection of the meter needle on the instrument.

### 15.4.6.2 Operation

The instrument must be calibrated before each field use. Calibration is performed by using a known concentration of a combustible gas that can be obtained from Mine Safety Appliances Company. Once the calibration gas is introduced to the instrument, adjustments can be made on an internal span control inside the explosimeter. If the explosimeter cannot be adjusted to read the standard, then the detector filament must be replaced.

To establish a zero background reading, the explosimeter should be prepared for operation in an area known to be free of combustible gases and vapors. A flush of fresh air should be passed through the instrument to zero the meter needle. The sampling line should then be placed at the point where the sample is to be collected, and the highest reading on the meter should be recorded. The graduations on the scale of the meter are in percentages of the lower explosive limit. A deflection of the meter needle between zero and 100 percent shows how closely the atmosphere being tested approaches the minimum concentration required for an explosion. When the needle deflects to the extreme right side of the meter during a test, the person performing the test can reasonably assume that the atmosphere being tested is explosive. If the needle deflects to the extreme right side and then quickly returns to a position within the scale or below zero, this movement indicates that the atmosphere tested has exceeded the concentration of the UEL. This means that an overabundance of the gas or vapor has displaced or consumed the "normal" air (oxygen levels of about 21 percent), creating an environment that will not explode but could explode if the oxygen levels return to normal; therefore, it is important to continue monitoring. The user should always have the instrument on until the field team has left the atmosphere being tested and a final flush of fresh air has passed through the explosimeter to be sure that the atmosphere has been thoroughly analyzed.

#### 15.4.6.3 Limitations and Warnings Associated with an MSA Explosimeter

As with all instruments, the user should appreciate the limits of the explosimeter's capabilities and should be sure to operate the instrument within those limits. The following represents several important limitations:

1. The instrument is not designed to work in an oxygen-enriched environment (oxygen above 25 percent), nor will it function properly in an oxygen-deficient atmosphere (below 19.5 percent). Therefore, it must be used in conjunction with an atmospheric oxygen indicator.

2. The instrument will not indicate the presence of explosive or combustible mists or sprays, such as lubrication oil, or explosive dusts, such as grain or coal dusts.

3. Care should be taken when sampling over liquids so the liquid is not drawn into the instrument.

4. The following substances may poison the detection filament: leaded gasoline, silanes, silicones, silicates, or any silicon-containing compound.

5. The relative humidity must be in the range of 10 to 90 percent.

6. The instrument has a tolerance of 40 percent. For example, a reading of 20 percent LEL could be as high as 28 percent or as low as 12 percent.

7. The instrument must not be switched on or off unless the user is in a known combustible-free atmosphere.

8. The explosive limits for many gases and vapors are far above the threshold limit values (TLVs) for those substances.

9. Fuming acids, such as sulfuric acid and nitric acid, will also poison the detection filament.

10. The instrument is typically calibrated with methane gas. Many other materials are explosive at concentrations below that of methane. Care must be used in a test atmosphere that may contain these types of materials. The readings obtained by the instrument are not specific. The readings indicate only that the atmosphere being measured is some percentage of the LEL of the calibration atmosphere. Therefore, the National Institute for Occupational

Safety and Health criteria shown below must be used in interpreting the readings when using the instrument in an atmosphere of unknown contaminants.

#### 15.4.6.4 NIOSH Criteria

NIOSH guidelines on the use of the explosimeter are as follows:

1. Ten percent LEL – Limit activities in area to those that do not generate sparks; wear non-sparking gear; use spark-proof equipment.

2. Twenty percent LEL – Limit all activities in area.

### 15.4.7 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 15.4.8 Information Sources

Mine Safety Appliances Company. "Instruction Manual, Model 260, Combustible Gas and Oxygen Alarm." Pittsburgh, Pennsylvania.

U.S. Environmental Protection Agency. *Standard Operating Guides*. December 1984.

NIOSH / OSHA / USCG / EPA. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities*. October 1985.

## 15.5 OXYGEN INDICATOR

### 15.5.1 Scope and Purpose

This subsection provides general guidance for the understanding, use, and application of an oxygen indicator. The methodologies that are described refer to oxygen indicators manufactured by Mine Safety Appliances Company.

### 15.5.2 Definitions

**Oxygen Indicator**
An instrument that provides a means to measure atmospheric oxygen concentrations. The volume percent for atmospheric oxygen is 20.95 percent.

**Partial Pressure**
The pressure that each gas exerts in a gas mixture (i.e., oxygen is 159 mmHg at sea level). Partial pressure is also temperature dependent.

### 15.5.3 Applicability

Wherever contaminants have been detected, a certain percentage of the atmosphere has been displaced, subsequently lowering the partial pressure of oxygen. In respiration, it is not the percentage of oxygen in the air, but rather its partial pressure that is important in sustaining life.

Oxygen-deficient atmospheres at hazardous waste sites often include confined spaces, such as abandoned warehouses where solvent drums are typically stored. Oxygen-deficient atmospheres could possibly be created during drum excavation in test pits where heavier-than-air vapors accumulate at the bottom of the test pit.

### 15.5.4 Responsibilities

Before taking the oxygen indicator into the field, the user should inspect and calibrate it to ensure its proper operation. If possible, maintenance and calibration should be restricted to one or two qualified individuals.

### 15.5.5 Records

Logbooks should record the oxygen indicator's checkout and calibration procedures. Although it is a relatively simple instrument to use, the oxygen indicator can be incorrectly operated if the user is not thoroughly familiar with its operation. An appropriate training and certification procedure must be developed and incorporated. The users must complete the training and be certified for operation before using the instrument in the field. Refresher courses should be obligatory every 6 months. Courses are offered by the manufacturer, by various commercial entities, and by EPA at their Cincinnati, Ohio, and Edison, New Jersey, facilities.

### 15.5.6 Procedures

#### 15.5.6.1 Theory

The MSA Oxygen Indicator tests the partial pressure of oxygen in the atmosphere. The actual sensing device consists of an oxygen-specific permeable membrane that allows oxygen to pass into the sensor until the partial pressures equalize on both sides of the membrane. Inside the sensor is an electrolyte solution that surrounds two electrodes. An oxidation-reduction reaction occurs in which the amount of current generated is directly proportional to the oxygen concentration. The change in current is detected by the meter circuit, and the needle is calibrated to indicate oxygen concentration in percentage, which is read out directly. The sensor is temperature compensated from 32°F to 104°F. The indicator response time is increased in temperatures beyond the compensated range, partially below 32°F.

The instrument must be calibrated before using it in the field. Calibration is performed by adjusting a calibration screw when the probe is exposed to fresh air. Readings should be checked every hour in sampling areas where the temperature is not constant to attain the greatest accuracy possible.

#### 15.5.6.2 Limitations and Warnings Associated with an MSA Oxygen Indicator

As with all instruments, the user should appreciate the limits of the oxygen indicator's capabilities and should be sure to operate it within those limits. The following represents several of the important limitations:

1. Condensation of moisture on the sensor face will cause low oxygen readings. To avoid this problem, allow the sensor to reach ambient temperature before taking readings.

2. Strong oxidants such as fluorine, chlorine, and ozone will lead to erroneously high oxygen readings when these oxidants are present in concentrations exceeding 5,000 ppm or 0.5 percent.

3. Concentrations of $CO_2$ greater than 1 percent will reduce sensor life.

4. Changes in barometric pressure because of altitude will also affect the meter reading. The instrument is calibrated for 20.8 percent oxygen at sea level (one atmosphere).

5. Relative humidity operating range is 10 to 90 percent.

6. The sensor must not be touched by hands or other objects; the membrane is easily damaged.

7. Fuming acids, such as sulfuric acid or nitric acid, will poison the probe.

8. Once exposed to air, the oxygen sensor has a shelf life of approximately 1 year.

#### 15.5.6.3 Recommended Action Levels

If the oxygen level is less than 19.5 percent, the inspection should be continued only with a self-contained breathing apparatus (SCBA) or a similar unit; the oxygen-deficient area should be identified.

If the oxygen level is more than 19.5 percent, the inspection can continue without breathing apparatus. If the cartridge will provide adequate sorbent efficiency, a cartridge respirator is acceptable. Also, the contaminant must have good warning properties, and must not react with the sorbent material in the cartridge.

If the oxygen level exceeds 25 percent, the area should be vacated, since an oxygen-rich atmosphere exists and an explosion or fire is possible.

#### 15.5.6.4 NIOSH Criteria

Oxygen levels lower than 19.5 percent require the use of supplied-air respirators.

### 15.5.7 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 15.5.8 Information Sources

Mine Safety Appliances Company. "*Instruction Manual, Model 260, Combustible Gas and Oxygen Alarm.*" Pittsburgh, Pennsylvania.

U.S. Environmental Protection Agency. *Standard Operating Guides.* December 1984.

NIOSH / OSHA / USCG / EPA. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities*. October 1985.

## 15.6 COMBINED COMBUSTIBLE GAS (EXPLOSIMETER) AND OXYGEN ALARM

### 15.6.1 Scope and Purpose

This subsection provides general guidance for the understanding, use, and application of a combined combustible gas and oxygen alarm. The methodologies refer to combined combustible gas and oxygen alarm instruments manufactured by Mine Safety Appliances Company.

### 15.6.2 Definitions

**Explosimeter**
An instrument used to test an atmosphere for concentration of combustible gases and vapors.

**Lower Explosive Limit (LEL)**
The minimum concentration of a gas or vapor in air by volume that will explode or burn when there is an ignition source.

**Upper Explosive Limit (UEL)**
The maximum concentration of a gas or vapor in air by volume that will explode or burn when there is an ignition source.

**Oxygen Indicator**
An instrument that provides a means to measure atmospheric oxygen concentrations. The volume percent for atmospheric oxygen is 20.95 percent.

**Partial Pressure**
The pressure that each gas exerts in a gas mixture (i.e., oxygen is 159 mmHg at sea level). Partial pressure is also temperature dependent.

### 15.6.3 Applicability

The combined combustible gas and oxygen alarm can be extremely useful, since both the combustible gas and oxygen alarm are incorporated into one unit. For example, when combustible vapors are present in sufficient concentrations to displace a certain percentage of the atmosphere, this condition should be reflected as a low reading on the oxygen indicator and an elevated reading on the explosimeter. In turn, the oxygen indicator also establishes the limits of oxygen concentration (19.5 percent to 25 percent) in which the explosimeter can function properly.

This instrument has been useful during installation of monitoring wells in and around landfills where methane gas is of concern. Confined spaces at hazardous waste sites, such as abandoned warehouses and storage sheds containing drums of volatile substances, pits, trenches, or sewers are prime examples of where the instrument has provided service.

### 15.6.4 Responsibilities

Before the instrument is taken into the field, it should be inspected and calibrated to ensure that it is operating properly. If possible, maintenance and calibration should be restricted to one or two qualified individuals.

### 15.6.5 Records

Logbooks should record the instrument checkout and calibration procedures. Although a relatively simple instrument to use, the oxygen alarm can be incorrectly operated if the user is not thoroughly familiar with its operation. An appropriate training and certification procedure must be developed and incorporated. The users must complete the training and be certified for operation before using the instrument in the field. Courses are offered by the manufacturer, various commercial entities, and by EPA at their Cincinnati, Ohio, and Edison, New Jersey, facilities.

### 15.6.6 Procedures

The procedures for the confined explosimeter and oxygen indicators are the same as for the separate instruments. The reader should refer to Subsections 15.4 and 15.5.

### 15.6.7 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 15.6.8 Information Sources

Mine Safety Appliances Company. "Instruction Manual, Model 260, Combustible Gas and Oxygen Alarm." Pittsburgh, Pennsylvania.

U.S. Environmental Protection Agency. *Standard Operating Guides.* December 1984.

NIOSH / OSHA / USCG / EPA. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities.* October 1985.

## 15.7 VAPOR DETECTION TUBES - DRAEGER GAS DETECTOR MODEL 21/31

### 15.7.1 Scope and Purpose

This procedure discusses the use of Draeger tubes to determine the concentrations of specific gaseous pollutants in the field.

### 15.7.2 Definitions

None.

### 15.7.3 Theory and Limitations

#### 15.7.3.1 Theory

A known volume of air is drawn through a reagent by using the pump and tube. The length of the color change observed in the tube translates to a ppm value.

#### 15.7.3.2 Limitations

1. Cross sensitivity is typical.

2. Readings are not specific; there is a large degree of error (35% at 1/2 the permissible exposure limit (PEL) to 25% at 1 to 5 times the PEL).

3. A slow response time is typical.

4. Shelf life can be maintained for 2 years by refrigerating tubes.

5. Operator error in "reading" the jagged edge where the contaminant meets the indicator chemical (end point) is a major source of inaccuracy.

### 15.7.4 Applicability

The colorimetric tube and pump measure the concentrations of specific inorganic and organic vapors and of gases that cause a discoloration which is proportional to the amount of material present. The detector tubes are specific for individual compounds, or groups of compounds, and require specific sampling techniques. This information is supplied with the tubes; it details the required sample volume, the proper tube preparation and insertion into the pump, and the applicability and limitations of the individual tube. Since several hundred different tubes are available, the user must consult the specific instructions for each tube.

## 15.7.5 Responsibilities

The SM is responsible for determining when the use of the Draeger tube is appropriate and for monitoring that the tube is properly set up for field sampling.

Personnel must be trained in the use of the detector tubes. Refresher courses should be obligatory every 6 months. Courses are offered by the manufacturer, various commercial entities, and by EPA at their Cincinnati. Ohio, and Edison, New Jersey, facilities.

## 15.7.6 Records

The comments dealing with the Draeger tube sampling episode should be detailed in the field logbook.

## 15.7.7 Procedures

### 15.7.7.1 Operation

A pump check should be performed each operational day. To complete this check, place an unbroken tube into the suction inlet of the pump and completely depress the bellows. The bellows should not completely extend (taut chain) in fewer than 30 minutes.

### 15.7.7.2 Field Use

- Break off both tips of the Draeger tube(s) in the break-off eyelet located on the front pump plate.
- Tightly insert the tube into the pump head with the arrow pointing toward the pump head. If multiple tubes are used (e.g., vinyl chloride), join the tubes with the rubber tube provided, then insert the tube into the pump head.
- Fully compress the bellows and allow the bellows to re-extend until the chain is taut. Repeat as often as specified in the tube operating instructions.
- Evaluate the tube according to instructions.

### 15.7.7.3 In-House Handling Procedures (Check In)

- Each unit on return from the field should be subjected to the following tests with results being entered in the logbook.
- The unit will be visually examined for surface dirt, deformities, cracks, and cuts.
- The pump integrity will be checked in the following manner:
    - Block the inlet with an unopened tube.
    - Fully compress; then release the pump bellows. If the bellows do not completely fill (limit chain slack) in 30 minutes, the unit is operating properly. If the unit does not pass the leak test, proceed as follows:

- Remove the pump plate.
- Unscrew the valve with the special wrench.
- Clean the valve in water and dry.
- Replace the disc if it is sticky, brittle, hard, or cracked.
- Reassemble and retest.

### 15.7.8 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 15.7.9 Information Sources

*Manual of Calibration, Maintenance, Service and Operation of NUS H&S Equipment and Monitoring Instruments.* November 1984.

U.S. Environmental Protection Agency. *Characterization of Hazardous Waste Sites, Volume II, Available Sampling Methods*. EPA 600/X-83-018. March 1983.

## 15.8 FIELD EQUIPMENT – RADIATION MONITORS

### 15.8.1 Scope and Purpose

This subsection provides guidance in the use and implementation rationale in determining possible exposure(s) to ionizing radiation by radiation monitors. Radiation or radioactivity is the property of the nucleus of an atom to spontaneously emit energy in the form of high-energy electromagnetic waves or particles. Types of radiation that are of concern are alpha particles, beta particles, and gamma and X-radiation.

Stable atoms of an element are composed of a dense nucleus containing an equal number of protons and neutrons. Surrounding the nucleus are clouds or orbits of electrons. The number of electrons in the atom of an element equals the number of protons. The number of neutrons in the atom can vary and, if it does, the atom is known as an isotope. Most isotopes are synthetic although some, such as Cs123 and U238, occur naturally in nature. In addition, most isotopes are radioactive; they are unstable and tend to transform into an atom of a different element called a "daughter" by releasing a particle (either alpha or beta particles) or by emission of gamma and X-rays. The type of energy released and the rate of this release (decay rate or half life) is particular to each isotope. If desired, the isotope can be identified by determining the type of energy released and by measuring the decay rate.

Radiation, unlike other chemical and physical exposures, has no real-time warning properties that are detectable by the human sensories. However, reliable radiation detectors are available.

All radiation detectors other than passive dosimeters (radiation badges) operate on the same principle; radiation causes ionization in the detection media. The ions produced are counted electronically, and a relationship is established between the number of ionizing events and the quantity of radiation present. Types of radiation detectors include the following:

- Ionization detection tubes are used primarily in high-range instruments, predominantly for detection of gamma and X-radiation.
- Proportional detection tubes inherently do not detect beta or gamma radiation; they are used primarily for detection of alpha radiation.
- Geiger-Mueller detection tubes are very sensitive to gamma and beta radiation.
- Scintillation detection media are crystal media that interact with radiation; they are highly sensitive to alpha and gamma radiation.

## 15.8.2 Definitions

**Radiation Alert–Mini**
Portable unit that detects ionizing radiation and that indicates, by using three-level scales, the actual radiation onsite with sound and light warnings and a level indicator.

**ROENTGEN**
The amount of gamma or X-radiation that will produce one electrostatic unit of charge in 1 cubic centimeter of dry air.

**Radiation Absorbed Dose (RAD)**
The quantity of radiation required for 100 ergs of energy to be absorbed by 1 gram of body tissue.

**Radiation Dose Equivalent in Humans (REM)**
A measure of the dose received in terms of its estimated biological effect(s) on humans.

**Thermoluminescent Dosimeter (TLD) Badge**
A clip-on badge containing a substrate impregnated with either lithium or calcium fluoride. These materials are phosphors that store energy when exposed to ionizing radiation. When the phosphor is heated to several hundred degrees centigrade, energy is released in the form of visible light that is measured with a photometer, providing an exposure reading.

## 15.8.3 Applicability

For the purpose of field work and site investigations, field teams should use several types of exposure monitors during field activities. It is conceivable that during different activities (recon versus sampling), disturbing different areas of a site may expose previously undetected radiation sources.

The cross conversion of ROENTGEN, REM, and RAD depends on a "quality factor" that is specific to each radioisotope and on the energy level of the radiation. With various forms of radiation, each has a "quality factor" that is based on its estimated biological effect on humans. It, therefore, stands to reason that each radioisotope has its own respective "quality factor."

Survey-type radiation detectors are normally calibrated against a cesium-137 gamma source. In essence, the detector is not calibrated for other isotopes. It does, however, serve as a good reference and relative indicator for other radiosotopes. The results of survey-type radiation detectors are usually displayed by a counter or audio response, along with a readout of milliroentgen per hour (mR/hr).

## 15.8.4 Responsibilities

The SM should see that field personnel are equipped with TLD badges and a Radiation Alert-Mini (or similar unit) during any aspect of field work. Health and safety personnel are responsible for addressing these safety subjects in the safety plan and for seeing that TLD badges are issued and collected quarterly.

## 15.8.5 Records

### 15.8.5.1 Thermoluminescent Dosimeter (TLD) Badge

The responsible health and safety manager or designee will maintain records of TLD issuance and results, as well as badges that are lost or exposed through nonfield (airport or dentist) activity.

### 15.8.5.2 Other Radiation Monitors

Health and safety personnel or their designees maintain records relative to the following:

1. Periodic calibration (according to factory specifications).
2. Major repairs (in which case the unit is to be labeled "Out of Service").
3. Usage in the field.
4. Site safety personnel will keep records of any above background readings and action taken (to be noted on the site safety follow-up report or by emergency phone call) to be submitted to the responsible health and safety manager.

## 15.8.6 Procedures

### 15.8.6.1 Radiation Alert – Mini

An example of a survey-type radiation detector is the Radiation Alert-Mini, manufactured by Solar Electronics, which uses a miniature geiger detector tube with a thin mica end window called the alpha window. This arrangement makes the Radiation Alert-Mini sensitive to all forms of radiation. The detector indicates all incoming radiation with an audio response and counter. The level of radiation is measured in milliroentgens per hour (mR/hr). At lower elevations natural background radiation can produce 10 to 20 counts per minute. The detector has three ranges (X1, X10, and X100) with two alarm lights that indicate counts of 10 and 30 percent for each range, e.g., .1 mR/hr and .3 mR/hr for the X1 range, and 1 mR/hr and 3 mR/hr for the X10 range, and so on. Checkout procedures are as follows:

1. Check to see the unit is "field-ready."
2. Check battery by switching to ON position. (**Note:** Field teams should bring extra batteries, especially for lengthy projects.)
3. Switch unit to AUDIO. A periodic beep and flash will indicate the unit is working, especially because of background radiation. (.01-.02 mR/hr) (**Note:** 10 to 20 CPM on unit.)

4. Set the scale on the unit so it falls within precautionary guidelines as follows:

   - If less than 2 mR/hr, continue investigation with caution.
   - If greater than 2 mR/hr, stop work and evacuate site.

(Note: Exact readings cannot be determined with most alert-minis. If readings above background are determined with the alert-mini, a radiation survey meter or equivalent must be used to determine exact readings before continuing operations.)

5. Note any areas that display above-background readings. If any site evacuation is needed, contact the responsible health and safety manager upon reaching an offsite "safe zone."

6. Limitations and precautions:

   - When testing for alpha radiation, be sure to position the alpha window about 1.4 inch from the material under test. Alpha particles will not penetrate more than about 1 inch of air and can be shielded by thin paper or similar material.

   - Avoid exposing the Radiation Alert-Mini directly to liquids and corrosive gases; also avoid extreme temperatures and direct sunlight.

   - Avoid contamination by not touching the surface of material being tested.

   - Calibration must be checked and performed by the factory. Annual calibration is recommended, although its operation should be checked periodically with a low-emission source such as mantals used in gas lanterns.

### 15.8.6.2 Thermoluminescent Dosimeter (TLD) Badge

**(Note:** The TLD badge measures total quarterly cumulative dosage to the body. *It is by no means to be used as a substitute for Radiation Alert-Mini or Thyac III, which measures actual site radiation.*

Radiation badges are commonly based on film dosimetry or chemical dosimetry. It is important to understand the usefulness and limitation of passive radiation dosimeters.

The conditions under which one must work are generally complex, ill defined, and irregular. Perhaps the most practical method, although less accurate than real-time monitors, is to monitor radiation exposure by using dosimeters. The dosimeter, or radiation badge, usually provides enough information that the absorbed dose can be inferred from the data. The dosimeter serves as a reliable assessment of radiation exposure on a time-weighed average and activity basis. Dosimetry is a convenient method of monitoring exposure for a whole crew of individuals where other methods would otherwise be impractical, if not impossible.

Upon receipt of TLD badges for each quarter, the responsible health and safety personnel implement the following procedures:

1. Distribute TLD badges to personnel subject to potential radiation exposure during field and laboratory activities.

2. Personnel who are issued a TLD badge wear the badge on their front pockets while onsite or performing laboratory work.

3. Field team members required to go through airport baggage checks (en route to or from the site) **MUST WEAR THE BADGE**. (Badges packed in luggage may become exposed if passed through X-ray machines.) Do not wear badges during visits to the dentist.

4. At the end of each quarter, health and safety personnel collect the badges and return them (including the control badge) to the manufacturer (or the designated company representative) and issue new badges for the coming quarter.

5. Limitations and precautions

- Dosimetry is a measure of after-the-fact exposures.
- Badges that are not worn by workers provide little information; compliance must be monitored.
- Badges that are exposed to direct sunlight for extended periods produce false readings.
- Badges that are exposed to ionizing radiation when not in use, as in the case of security checks at airports and in the presence of color TV and microwave ovens, will produce false positive readings.

### 15.8.6.3 Model 490 Victoreen Thyac III Survey Meter

The Model 490 is a pulse-count ratemeter and power supply. With the pancake detector probe, it acts as a survey meter for alpha-beta-gamma radiation. Its range of operation is 0-80,000 cpm or 0-20 mR/hr approximate radiation intensity with appropriate detector.

Use and Operation

The instrument should be used only by persons who have been trained in the proper interpretation of its readings and in the appropriate safety procedures to be followed in the presence of radiation. Training courses are mandatory for all field personnel, and refresher courses should be obligatory every 6 months. Failure to follow instructions may result in inaccurate readings and/or user hazard. Indicated battery and operational (check source) tests must be performed before each use to ensure that the instrument is functioning properly. Failure to conduct periodic performance tests in accordance with ANSI N323-1978, paragraphs 4.6 and 5.4, and failure to keep records thereof in accordance with paragraph 4.5 of the same standard could result in erroneous readings of potential danger. Do not connect or disconnect any detector while the instrument is on. Wait 2 minutes after the instrument is turned off before connecting or disconnecting any detector. Failure of transistors will occur if these instructions are not followed.

The Thyac III is designed for 100 hours of continuous use on two "D" cell batteries and longer with intermittent use. Trained personnel are required to interpret its readings. The user must be sure to read the instruction manual before using. The instrument is in a weatherproof case, which contains the two operating controls (the function switch, and the response switch) on top.

A low-intensity beta check source is provided on the case. Temperature limits are -30° to +50°C (limits for batteries may be different). The check source may be used with a headset or an audio speaker; it may be put in a plastic bag, when appropriate, to prevent contamination.

Maintenance

Do not store the instrument with the batteries inside. Replace the batteries as indicated during the battery check performed before each use. Recalibrate the instrument periodically according to manufacturer's specifications.

#### 15.8.6.4 Eberline Model E-120 Radiation Monitor

The Model E-120 is a gamma response radiation monitor that has dual scales (0-5 mR/hr and 0-6 CPM). This unit has three range multipliers (x0.1, x1.0, and x10.0) and has adjustable response times. The general operating procedures are as follows:

Field Operation

- Switch to the battery check position to indicate the battery condition.
- Check the instrument's operation by placing a check source in a repeatable position adjacent to the detector. Move the selector switch to a range that will give an upscale reading greater than 10 percent of scale. Adjust the response control to minimize the erratic meter movements.
- Log the instrument's response value on the green tag.

In-House Handling Procedures (Check In)

- When each instrument returns from the field or at alternate 6-month maximum storage intervals,
  - Clean and visually examine the instrument for defects
  - Check its battery status
  - Validate its response to an operation check source
  - Enter the above data and any green tag data into the appropriate logbook
- At least once per year, ship each instrument to the manufacturer for recalibration.

### 15.8.7 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 15.8.8 Information Sources

Sax, N.I.. *Dangerous Properties of Industrial Material.* 6th ed. New York: Van Nostrand Reinhold Co. 1984

CH2M HILL. *Field Surveillance Equipment.* 1984.

## 15.9 PERSONAL SAMPLING PUMPS

### 15.9.1 Scope and Purpose

This subsection provides general guidance regarding the plans for, method of selection, and use of personal sampling pumps for field investigations of hazardous waste sites.

### 15.9.2 Definition

**Personal Sample**
An air sample that is collected by a device worn on the worker; the device measures actual exposure during the work routine.

### 15.9.3 Applicability

This subsection discusses the use of sampling pumps for personal monitoring purposes. These guidelines are based on the objective of determining the potential exposure to a worker of air contaminants. Subsection 11.6 contains information on area sampling of ambient air.

### 15.9.4 Responsibilities

Field personnel must be adequately trained in the operation of personal sampling pumps. Refresher courses should be obligatory every 6 months. Courses are offered by the manufacturer, various commercial entities, and by EPA at their Cincinnati, Ohio, and Edison, New Jersey, facilities.

### 15.9.5 Records

Training records, maintenance records, and calibration records must be generated and maintained by the responsible organization. Specific records of field use should be noted in field notebooks as suggested in Sections 6 and 17.

### 15.9.6 Procedures

#### 15.9.6.1 Preliminary Considerations

The planning, selection, and implementation of any monitoring program using personal sampling pumps require clearly defined objectives. The following considerations must be examined to define what the user wants to measure:

- Worker exposure versus ambient air
- Long-term (8 hours) versus acute (momentary releases) exposure

- Vapors versus particulates

The sampling pump that is selected must also be lightweight, portable, and not affected by motion or position.

### 15.9.6.2 Description and Application

Personal sampling pumps come in various models. Several models offered by MSA include the Monitaire Samplers; Models S and TD; Model C-210 Portable Pump; and the Fixt-Flo Pump, Model 1. All these models consist of a compact pump that may be clipped to the worker's belt or carried in a shirt pocket so that continuous air sampling can be made. A sampling head containing the sorbent tube, filter, or other collection medium is clipped to the lapel of the worker as close to the breathing zone as possible.

The contaminant(s) of interest will determine the type of collection medium used with the pump. Organic and inorganic vapors, as well as particulate in the breathing zone of the worker, may be measured.

MSA Colorimetric Detector Tubes are available for measuring toxic concentrations of ammonia, carbon dioxide, carbon monoxide, chlorine, hydrogen chloride, hydrogen cyanide, hydrogen sulfide, mercury vapor, nitrogen dioxide, ozone, sulfur dioxide.

Charcoal sampling tubes are also available to provide efficient collection of organic and mercury vapors for subsequent analysis using laboratory instrumentation.

The organic vapor tube will collect compounds such as benzene, carbon tetrachloride, chloroform, dioxane, ethylene dichloride, trichloroethylene, and xylene. The mercury vapor sampling tube collects both elemental and chemically bound mercury vapors, plus particulates containing mercury.

All the above-mentioned MSA sampling pumps are rechargeable battery-operated diaphragm pumps. Flowrates may be adjusted on all models.

As general guidance, the following procedures should be followed when using personal sampling pumps:

1. Fully charge the pump.
2. Calibrate the pump.
3. Make sure assembly does not leak by assembling the unit, covering the inlet to the sampling device, and drawing a vacuum on the assembly.
4. If no leaks occur, the sampler is ready for use.

Manufacturer's instructions should be followed for more complete guidance on using a specific model.

Certain information should be recorded in a field notebook when a personal sampling pump is used. This may include, but not be limited to the following:

- Date
- Name

- Site
- Pump number
- Type of sample
- Time sampler started
- Time sampler turned off
- Flowrate
- Weather conditions

### 15.9.7 Region-Specific Variances

No region-specific variances have been identified; however, all future variances will be incorporated in subsequent revisions to this compendium. Information on variances may become dated rapidly. Thus, users should contact the regional EPA RPM for full details on current regional practices and requirements.

### 15.9.8 Information Sources

*MSA Safety Equipment Catalog.* 600 Penn Center Boulevard, Pittsburgh, Pennsylvania 15235.

Cralley and Cralley. *Patty's Industrial Hygiene and Toxicology, Volume III.* 1979.

U.S. Steel Corporation. Environmental Health Services. *Environmental Health Monitoring Manual.* 1973.

## 15.10 OTHER MONITORING DEVICES

### 15.10.1 Electrochemical Gas Detector

There are many manufacturers of gas detector monitors that use electrochemical cells for detection of toxic inorganic gases. Many of these detectors are mixed oxide semiconductors (MOS) of a proprietary design, although many are of a galvanic cell type, as previously described for the MSA oxygen indicator, but specific to the analyt gas.

Typically, one manufacturer may provide a monitor with one or more replaceable cells. In certain instances, MOS cells for different gases can be interchanged in the same monitor. Electrochemical gas detectors are quite compact, are battery operated, have lower explosive detection (LED) readouts, and have audio alarms for present concentrations.

The Monitor Compur 4100 is an example of the MOS-based electrochemical gas detection system. The monitor offers MOS cells for hydrogen sulfide ($H_2S$), hydrogen cyanide (HCN), nitrogen dioxide ($NO_2$), and phosgene ($COCl_2$).

The monitor system is designed in particular to monitor and alert the user when threshold limit values (TLV) are exceeded as follows:

$H_2S$ – 10 ppm
HCN – 10 ppm
$NO_2$ – 5 ppm
$COCl_2$- – 0.1 ppm

Of greatest consequence many times to site investigations are phosgene and hydrogen cyanide. Electrochemical gas detection such as the monitox system offers a real-time measure of phosgene and hydrogen cyanide. Neither of these chemicals has warning properties (i.e., odor, taste) at TLV levels.

### 15.10.1.1 Limitations and Precautions

- Cross sensitivity to other gases can trigger false alarms.
- Chemical filter (activated charcoal) for the $COCl_2$ cell needs to change frequently if monitoring is in the presence of $H_2S$, HCl, and $CL_2$.
- High concentration of analyt gas, typically 100 times the TLV, can irreparably change the sensor cell.
- Sensor cells must be protected from excessive moisture and dust-laden air.
- Service life of sensor cells is typically 6 months during normal use.

## 15.10.2 Passive Dosimeters

The use of passive dosimeters or gas badges is a recent development in sampling. No energy or action is required to take the sample. Currently badges are available to sample from 15 minutes to 8 hours. These badges can be used for sampling organic vapors, formaldehyde, mercury vapor, ammonia, sulphur dioxide, and nitrogen dioxide.

Most passive dosimeters work on the principle of diffusion. Gases and vapors enter the monitor by diffusion and are absorbed by a sorbent medium in the interior of the badge. The amount of gas or vapor adsorbed is determined by expo sure time and concentration present in the monitored environment. A measured volume of an eluent is added to the monitor to desorb and dissolve the contaminants. An aliquot of the eluent solution is then analyzed by analytical procedure specific to the contaminant. The weight of the contaminant is used in conjunction with the diffusion constant, as determined by the badge manufacturer, to calculate the time-weighted average worker exposure.

## 15.10.3 Miniram Monitor

The MINIRAM (Miniature Real-Time Aerosol Monitor) is a compact, personal size, airborne particulate monitor whose operating principle is based on the detection of scattered (nephelometric principle) electromagnetic radiation in the near infrared. The radiation scattered by airborne particles passing freely through the open sensing chamber of the monitor is sensed by a photovoltaic detector. An optical interference filter screens out light whose wavelength differs from the narrow-band pulsed source. Aerosol concentration is displayed as milligrams per cubic meter every 10 seconds. The readings are stored and integrated to provide time-weighted averages.

Calibration of the monitor is performed by the factory against a filter gravimetric reference. The MINIRAM has application to measuring all forms of aerosols: dusts, fumes, smokes, fogs, etc. The MINIRAM is unique in that it provides real-time semi-quantitative measurements of aerosol concentrations, unlike filtration-gravimetric methods, which require both time and laboratory facilities to complete.

The MINIRAM has particular application in monitoring ambient air for toxic aerosols or toxic elements associated or transported by aerosols.

# SECTION 16

# DATA REDUCTION, VALIDATION, REPORTING, REVIEW, AND USE

## 16.0 GENERAL

This section discusses the data validation procedures that are specific to the Contract Laboratory Program (CLP). A more detailed discussion is available in the *User's Guide to the CLP*. The section also describes data validation procedures that the Site Manager uses in evaluating any laboratory data.

## 16.1 NATIONAL CONTRACT LABORATORY PROGRAM – LABORATORY DATA

### 16.1.1 Scope and Purpose

This subsection summarizes the validation procedures used to review laboratory analyses conducted for the Contract Laboratory Program (CLP). The CLP offers routine analytical services (RAS) that deliver analyses of the Target Compound List (TCL) organic compounds, Target Analyte List (TAL) inorganic parameters, and dioxin (2,3,7,8-TCDD). Special analytical services (SAS) also are available through the CLP. These include customized or specialized analyses, quick turnaround analyses, verification analyses, analyses requiring lower detection limits than RAS methods provide, identification and quantification of nonpriority pollutant and non-TCL or non-TAL constituents, general waste characterizations, and analysis of nonstandard matrices. The validation process compares a body of data against a set of performance criteria to determine consistency and applicability to specific purposes.

### 16.1.2 Definitions and Abbreviations

**Contract Laboratory Program (CLP)**
The reader should see the *User's Guide to the CLP*.

**Target Analyte List (TAL) Inorganics**
23 metals and cyanide (See Section 7 of this compendium for a listing or consult the *User's Guide to the CLP.)*

**Target Compound List (TCL) Organics**
127 organic compounds are included on the TCL (35 volatiles, 65 semivolatiles, and 27 pesticides or PCBs) (See above.)

**Routine Analytical Services (RAS)**
(See the *User's Guide to the CLP*.)

**Sample Management Office (SMO)**
(See the *User's Guide to the CLP*.)

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. This person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

**Special Analytical Services (SAS)**

**Special Analytical Services (SAS)**
(See the User's *Guide to the CLP*.)

### 16.1.3 Applicability

The procedures in this section apply to analyses conducted by laboratories in EPA's Contract Laboratory Program.

### 16.1.4 Responsibilities

Scheduling of analyses is the responsibility of the EPA Regional Sample Control Centers (RSCC). Contract laboratories analyze samples from Superfund sites under the CLP and send the reports to the Environmental Services Division (ESD). Assessment of the laboratory data package is authorized by the RSCC, which approves release of the information to the SM. Before release for use, all CLP data are reviewed and approved by the ESD of the specific EPA regional office or by its contractors to assess the applicability of each data package to its intended use. Data validators will assess the laboratory product as specified in the referenced protocols and region-specific protocols, and the validators will then make a recommendation to the ESD's regional office. ESD provides technical oversight and assistance and makes the final decision on qualifications of the laboratory data. No data are considered usable without notifying the ESD of the validation.

### 16.1.5 Records

The CLP RAS protocols for analyzing TCL organics, TAL inorganics, and dioxin in Superfund samples specify the report format. Examples of laboratory report forms and validation procedures for TCL organics, TAL inorganics, and dioxin are given in Appendix B, "RAS Deliverables and Data Reporting Forms," of the *User's Guide to the CLP*. Several other lengthy examples are available to the SM, such as EPA's analytical statements of work (see information sources). Laboratory report forms for SAS analyses are specified in the user-provided analytical protocol and associated quality control (QC) procedures for each SAS request.

### 16.1.6 Procedures

Detailed procedures for CLP data reduction, validation, and reporting are found in the *User's Guide to the CLP*. Specific procedures for CLP validation of data are found in the standardized organic, inorganic, and dioxin CLP analytical methods; each CLP user is provided with a sample data package that contains documentation of a series of QC operations that permit an experienced chemist to determine the quality and applicability of the data. Each EPA region and CLP laboratory has established additional QC and data validation procedures.

## 16.2 DATA VALIDATION

### 16.2.1 Scope and Purpose

This section discusses both sources of data errors and approaches to reduce these errors.

### 16.2.2 Definitions

The reader should see Subsection 6.1.2.

### 16.2.3 Applicability

The procedures discussed below can be used by the SM on any project, since measurements made have inherent limitations that include the equipment and procedure used, the skill of the person performing the analysis, and the conditions under which it is performed. Environmental measurements are often trace analyses made at extremely low concentrations. These measurements are subject to chemical and physical interferences, instrument limitations, and uncertainties that affect the accuracy of the determination. It is essential, therefore, to minimize these factors so that the measurements accurately reflect the character of the sample collected. A systematic process to consider when measuring environmental contaminants is recommended by the American Chemical Society in "Guidelines for Data Acquisition and Data Quality Evaluation in Environmental Chemistry." This process considers the planning, measurement, calibration standardization, quality assurance, statistical procedures, and documentation needed for high-quality analytical chemical data.

### 16.2.4 Responsibilities

Site Managers are ultimately responsible for obtaining valid, usable data. They are assisted by project personnel, corporate quality assurance / quality control (QA/QC) personnel, and the analyzing laboratories.

### 16.2.5 Records

Data validation records are included as part of the QA/QC package.

### 16.2.6 PROCEDURES

#### 16.2.6.1 Exploratory (Qualitative) Investigations

Generally, analytical measurements are considered to follow a continuum of analyte concentration as shown in Exhibit 16-1. At some finite concentration, the analyte is detected at an instrument response level greater than the instrument background noise level or field blank value. Qualitative measurements depend on both the analytical method used and the concentration of the analyte in the sample.

#### 16.2.6.2 Quantitative (Remedial, Enforcement Site Dynamics) Investigations, Reduction, and Validation

As shown in Exhibit 16-1, the numerical significance of the apparent analyte concentration increases as the analyte signal increases above the LOD. The limit of quantitation (LOD) is determined by the expression

$$S_t - S_b \quad \geq \quad K_q^s$$

where:

$K_q$ = quantitation factor, which is usually equal to 10

$$LOQ = S_q$$

Sample analyte concentrations in the range of 3 to 10 $s$ are highly variable and are more consistent at values greater than 10 $s$. Every analytical system contains sources of inaccuracy and imprecision that are demonstrated in the variability of replicate analyses. These inaccuracies include both systematic and random errors. Random errors are the result of (a) inherent limitations of the equipment, (b) limitations of observations, and (c) lack of care in making measurements. Random errors can be above or below the sample mean. Replicate analyses are recommended to minimize the effect of possible errors. Examples of random errors include weighing uncertainties, aliquot variabilities, sample heterogeneity, and instrument noise.

Systematic errors are consistent and bias the measurement in one direction (unless two or more systematic errors are present that affect the data in differing directions). Examples of such errors include instrument calibration error, uncompensated instrument drift, or operational errors.

These errors combine to produce measurement variability that is reflected by the indicators of measurement quality, precision, and accuracy.

- Precision is the degree of agreement among individual measurements made under prescribed conditions using a single test procedure.
- Accuracy is the difference between an average value and the true value, when the latter is known or assumed.

Precise measurements reflect the proper use of good laboratory practices, proven methodology, and low noise instrumentation. Accuracy is confirmed by using standard reference materials and participating in interlaboratory comparison activities. Prepared standards and performance samples are available from the U.S. National Bureau of Standards, U.S. Environmental Protection Agency, U.S. Food and Drug Administration, U.S. Department of Agriculture, and various commercial sources.

### 16.2.6.3 Data Review and Use

The SM will perform the following for data review:

- Review data summaries and reports for transcriptional and typographical errors.
- Review and determine if sampling protocols were appropriate.
- Review and compare the data against the field and trip blanks to detect contamination from sampling (see Subsection 16.2.3).
- Review and compare field sampling replicates.
- Review laboratory QC including laboratory blanks, spike recovery, method standards, and duplicates. Are the data usable from a QC perspective?

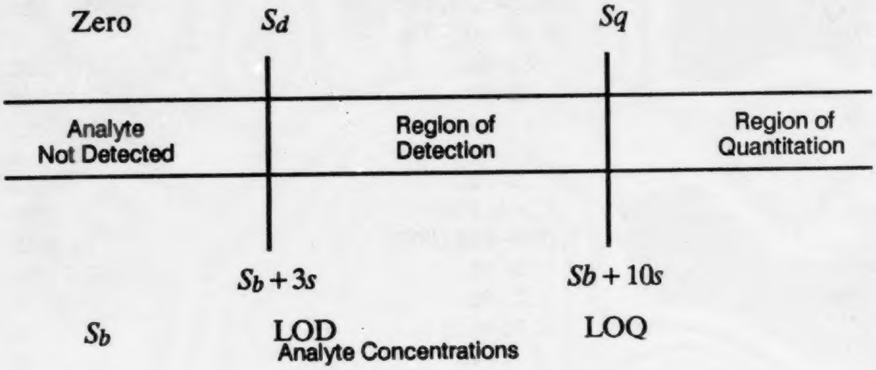
## Exhibit 16-1
## CONTINUUM OF ANALYTE CONCENTRATION

$$S_t - S_b \quad \geq \quad K_d^s$$

where:

$S_t$ = gross signal
$S_t$ = blank signal
$K_d$ = response factor
$s$ = standard deviation of measurement

This expression defines the limit of detection (LOD) where $K_d$ is generally accepted as a value of 3.


Zero
$S_d$
$S_q$
Analyte Not Detected
Region of Detection
Region of Quantitation
$S_b + 3s$
$S_b + 10s$
$S_b$
LOD
LOQ
Analyte Concentrations

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(1)*Anal. Chem.*, 1980, 52, 2242.

## Exhibit 16-2
## THE CONTENT OF VARIOUS ELEMENTS IN SOILS

| Element | Common Range for Soils (ppm) | Selected Average for Soils (ppm) |
|---|---|---|
| Silver | 0.01-5 | 0.05 |
| Aluminum | 10,000-300,000 | 71,000 |
| Arsenic | 1-50 | 5 |
| Boron | 2-100 | 10 |
| Barium | 100-3,000 | 430 |
| Beryllium | 0.1-40 | 6 |
| Bromine | 1-10 | 5 |
| Carbon | | 20,000 |
| Calcium | 7,000-500,000 | 13,700 |
| Cadmium | 0.01-0.70 | 0.06 |
| Chlorine | 20-900 | 100 |
| Cobalt | 1-40 | 8 |
| Chromium | 1-1,000 | 100 |
| Cesium | 0.3-25 | 6 |
| Copper | 2-100 | 30 |
| Fluorine | 10-4,000 | 200 |
| Iron | 7,000-550,000 | 38,000 |
| Gallium | 5-70 | 14 |
| Germanium | 1-50 | 1 |
| Mercury | 0.01-0.3 | 0.03 |
| Iodine | 0.1-40 | 5 |
| Potassium | 400-30,000 | 8,300 |
| Lanthanum | 1-5,000 | 30 |
| Lithium | 5-200 | 20 |
| Magnesium | 600-6,000 | 5,000 |
| Manganese | 20-3,000 | 600 |
| Molybdenum | 0.2-5 | 2 |
| Nitrogen | 200-4,000 | 1,400 |
| Sodium | 750-7,500 | 6,300 |
| Nickel | 5-500 | 40 |
| Oxygen | | 490,000 |
| Potassium | 200-5,000 | 600 |
| Lead | 2-200 | 10 |
| Rubidium | 50-500 | 10 |
| Sulfur | 30-10,000 | 700 |
| Scandium | 5-50 | 7 |
| Selenium | 0.1-2 | 0.3 |
| Silicon | 230,000-350,000 | 320,000 |
| Tin | 2-200 | 10 |
| Strontium | 50-1,000 | 200 |

## Exhibit 16-2
(continued)

| Element | Common Range for Soils (ppm) | Selected Average for Soils (ppm) |
|---|---|---|
| Titanium | 1,000-10,000 | 4,000 |
| Vanadium | 20-500 | 100 |
| Yttrium | 25-250 | 50 |
| Zinc | 10-300 | 50 |
| Zirconium | 60-2,000 | 300 |

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Source: W. Lindsay. Chemical Equilibrium in Soils.
New York: John Wiley and Sons. 1979.

- Delete unusable data and attach appropriate qualifiers to usable data. Explain limitations of qualified data.
- Review and summarize detection limits for nondetectable results.
- Review detection limits for positive but nonquantifiable data. Are appropriate qualifiers assigned?
- Review sampling design for dealing with media variability.

Background concentrations are important in the identification of site specific contamination. For each medium or operable unit, the reader should consider the following:

- Are site-specific background samples available?
- Are the data of sufficient quality to estimate site-specific background concentrations?
- If background data are lacking, can local, regional, or national averages be found and used?

It is important to understand the "background" levels of chemicals in environmental media (air, surface water, groundwater, and soil) so that remedial actions may distinguish between the elimination of all risks and the reduction of risks to levels normally associated with the area.

"Background" is defined as the "normal ambient environmental concentration of a chemical." Background includes "natural" background and the contribution from anthropogenic (human-made) sources other than the site. "Natural" background is the range of concentrations of chemicals (primarily inorganics) naturally occurring in the environmental media. These concentrations may vary from aquifer to aquifer, depth to depth within one creek, and soil type to soil type. Anthropogenic sources include auto exhaust emissions, industrial discharges, and highway runoff.

Site-specific background samples should be taken for each environmental medium. These samples should be representative of the media on the site and should be taken at a location that is not influenced by the site. It is especially important in urban areas to take samples that can differentiate between site sources and other urban sources. When selecting the location and number of background samples, consider the variability of the medium, the number required for statistical validity, and the size of the area being defined. A minimum of three background samples should be taken in each identifiably different medium (i.e., shallow aquifer versus deep aquifer). Background values can be presented as a range, a mean, or a median; when appropriate, the confidence intervals around the mean. The appropriate measure depends on the ultimate use of the information.

If site-specific background values are not available, the reader should consult the following categories of information sources as a means of approximating background. The sources are presented in order of preference as follows:

1. Other local values, including those from other background samples taken at nearby Superfund sites; local surveys by the soil conservation service, U.S. Geological Survey (USGS); local universities; or other area-specific data sources, such as doctoral theses
2. Regional ranges and averages from USGS or other sources
3. Natural concentration ranges and averages in soil (see Exhibit 16-2)

Professional judgment will have to be exercised in selecting background values and in deciding which samples reflect site sources and which samples are consistent with background.

Once the range of background has been established, evaluation of remedial alternatives and estimation of risk can proceed.

## 16.3 REGIONAL VARIATIONS OF DATA VALIDATION

Each EPA region has developed variations of the CLP validation protocols for organics, inorganics, and dioxins. Because information on variances can become dated rapidly, the user should contact the EPA RPM or the RSCC that is within the ESD to obtain specific information on exceptions to these protocols. Future changes in variances will be incorporated in Revision 01 of this compendium.

## 16.4 INFORMATION SOURCES

U.S. Environmental Protection Agency. *Laboratory Data Validation, Functional Guidelines for Evaluating Organics Analyses.* Technical Directive Document No. HQ-8410-01. Hazardous Site Control Division. May 1985.

U.S. Environmental Protection Agency. *Statement of Work, Dioxin Analysis, Soil/Sediment and Water Matrices, Multi-Concentrations, Selected Ion Monitoring (SIM) GC/MS Analysis.* IFB WA 86-K356. Sample Management Office. September 1986.

U.S. Environmental Protection Agency. *Statement of Work, Organics Analysis, Multi-Media, Multi-Concentration.* IFB WA-87J001, J002, J003. Sample Management Office. October 1986.

U.S. Environmental Protection Agency. *Statement of Work, Inorganics Analysis, Multi-Media, Multi-Concentration.* IFB WA-85J839. Sample Management Office. July 1985. (Note: Inorganic statement of work will be updated with a new IFB to be issued in the summer of 1987.)

U.S. Environmental Protection Agency. *User's Guide to the Contract Laboratory Program.* Office of Emergency and Remedial Response. December 1986.

# SECTION 17

# DOCUMENT CONTROL

## 17.1 SCOPE AND PURPOSE

This section describes procedures for the identification and control of documents that may affect the product quality for project activities. The procedures established should ensure that documents are reviewed for adequacy, completeness, and correctness and for release by authorized personnel. Changes to documents should be reviewed and approved by the authorized personnel that perform the original review and approval process or by their designees. Provisions should include identification and distribution of controlled documents; identification of personnel, position, or organizations responsible for preparing, reviewing, approving and issuing documents; and establishment of a document filing, numbering, and inventory system.

## 17.2 DEFINITIONS

**Accountable Documents**

Those documents where there is reasonable belief that they will be used as evidence during litigation. In addition to controlled documents, these documents include logbooks, field data records, sample tags / labels, chain-of-custody records, bench cards, photographs, and correspondences that contain project data of evidentiary nature.

**Controlled Documents**

Those documents that describe activities affecting quality which will be used for evidentiary purposes during litigation. These documents are released by authorized personnel and distributed for use by the individuals performing the activities.

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

## 17.3 APPLICABILITY

This procedure is an applicable method to appropriately maintain the controlled and accountable evidentiary documents.

## 17.4 RESPONSIBILITIES

The originating organization will be responsible for identifying and maintaining the controlled documents in accordance with this or other quality-assurance-approved procedures.

## 17.5 RECORDS

Records provide the direct evidence and support for the necessary technical interpretations, judgments, and discussions concerning project activities. These records, particularly those that are anticipated to be used as evidentiary data, must directly support current or ongoing technical studies and activities and must provide the historical evidence needed for later reviews and analyses. The control of records is essential in providing evidence of technical adequacy and quality for all project activities. Records that furnish documentary evidence related to quality assurance activities will be specified, prepared and maintained. Other records to be generated during the project are specified in the work plan or task outline. Records must be legible, identifiable, and retrievable and will be protected against damage, deterioration, or loss. Requirements and responsibilities for record preparation, transmittal, distribution, retention, maintenance and disposition must be in accordance with quality-assurance-approved instructions such as those identified in this procedure.

## 17.6 PROCEDURES

### 17.6.1 Project Files

Project files are established upon issuance of Technical Directive Documents (TDDs), Work Assignments (WAs), or award of a contract. Each project file should be identified according to site name and TDD / WA / contract number or by other appropriate means that have been documented and approved by the Site Manager (SM) or higher authority.

The SM is responsible for assuring the collection, assembly, and inventory of all documents related to the project. The SM will designate a document custodian who will be responsible for record maintenance.

The document custodian is responsible for itemizing and, if the project size warrants, giving to the accumulated documents a unique sequential docket number. Each docket number should be logged in on a file inventory form (Exhibit 17-1). Documents should be placed into segregated file folders according to the controlled document project Individuals who remove documents from the project file should sign out the document, give the date documents were removed, and enter the date that the documents were returned to the project file.

Access to project files must be controlled to restrict nonproject personnel from having free and open access. An authorized access list should be placed on the central filing room door or outside each individual filing cabinet and should name the personnel who have unrestricted access to the files. Personnel not identified on the authorized access label must obtain project file access from the document custodian or designee.

The document custodian or designee must assure that the central filing room and individual filing cabinets are locked at the end of each day.

### 17.6.2 Document Identification and Numbering

Every controlled document should have a unique identifier (number).

Each work plan should be identified as to project and task number (TDD/WA number), revision level number, and report status (draft / final).

Procedures and instructions must be identified and referenced as to their origination or preparer, the approving organization or personnel, the effective date, and the revision level.

## Exhibit 17-1
## FILE INVENTORY

Site Name ____________

JOB No. ____________

TDD NO. ____________

Date ____________

| Docket Number | Date of Entry | Title of Document |
|---|---|---|
| | | |
| | | |
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| | | |
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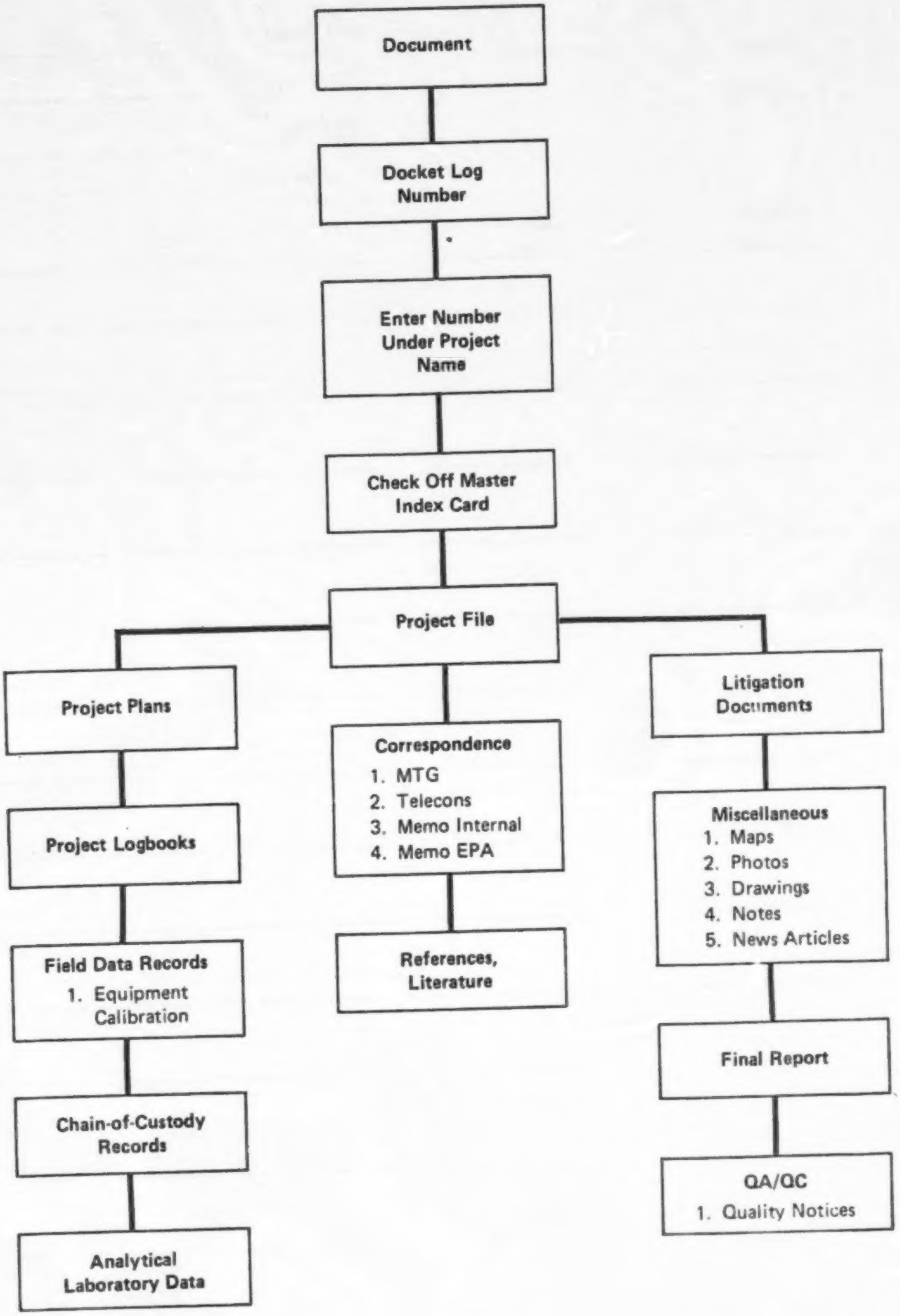
| | | |

## Exhibit 17-2
## CONTROLLED DOCUMENT PROJECT FILES PROCEDURES


Document
Docket Log Number
Enter Number Under Project Name
Check Off Master Index Card
Project File
Project Plans
Project Logbooks
Field Data Records
1. Equipment Calibration
Chain-of-Custody Records
Analytical Laboratory Data
Correspondence
1. MTG
2. Telecons
3. Memo Internal
4. Memo EPA
References, Literature
Litigation Documents
Miscellaneous
1. Maps
2. Photos
3. Drawings
4. Notes
5. News Articles
Final Report
QA/QC
1. Quality Notices

Each procurement document should have a sequential purchase order number or subcontract number assigned to it.

Accountable documents used by employees must be uniquely identified by serialized number or by other appropriate means. Each accountable document must be listed in a project's document inventory at the completion of each task or assignment.

Black waterproof ink must be used to record all data on or in serialized accountable documents.

Documents related to field activities, such as sample tags/ labels, chain-of-custody forms, and logbooks, will be numbered serially and their distribution will be controlled. This control is usually through the EPA office issuing the documents. The reader should refer to Section 4 of this compendium.

## 17.6.3 Document Distribution

Controlled documents, such as manuals, procedures, instructions, and guidelines that are required for use in performing project work, should be distributed on the basis of a written, approved distribution list using a formal transmittal form, such as shown in Exhibit 17-3, with a return receipt required.

### 17.6.3.1 Document Distribution to Third Parties

All project documents generated by the Superfund contractors are the property of EPA. The distribution of such documents to state agencies, potential responsible parties, lawyers, other regulatory agencies, or branches within the EPA must be in accordance with recommended regional EPA practices. Requests for document distribution should be in the form of a TDD, WA, or memorandum from EPA.

Distribution of internal project documents, including but not limited to photographs, logbooks, work plans, operating guidelines, sampling procedures, documentation protocols, and health and safety procedures, should be inventoried onto a chain-of-custody form by recording the transfer of the requested documents. A document transmittal form should also accompany the requested information and must record the receipt of said information as specified by the EPA. The originating request to transmit the information must come from the EPA. Otherwise, all requests from outsiders must be referred to the EPA.

The return receipt must be documented on the controlled document transmittal log.

## 17.6.4 Revisions to Documentation

Major revisions to documents are subject to the same level of review and approval as the original document. Distribution of revised documents should include all holders of the original document.

Minor changes to documents, such as inconsequential editorial corrections, do not require that the revised documents receive the same review and approval as the original documents; however, they must be reviewed and approved at the highest level previously involved in review.

## Exhibit 17-3
## FORMAL TRANSMITTAL FORM

*DOCUMENT TRANSMITTAL*

| | |
|---|---|
| TO: | DATE: |
| | REFERENCE NUMBER |

SENDER:

THE FOLLOWING DOCUMENT(S) IS TRANSMITTED TO YOU FOR: ☐ USE ☐ RECORDS ☐ INFORMATION

| TITLE/I.D. NO. | REV. NO. | NO. OF COPIES | CONTROLLED NUMBERS | UNCONTROLLED NUMBERS |
|---|---|---|---|---|
| | | | | |

NOTE:

☐ ABOVE DOCUMENT(S) IS TO BE USED FOR WORK PLAN.
☐ ABOVE DOCUMENT(S) IS RESTRICTED TO USE ONLY FOR WORK PLAN.
☐ DESTROY PREVIOUS REVISION OF THE ABOVE DOCUMENT(S)
☐ RETURN PREVIOUS REVISION OF THE ABOVE DOCUMENT(S) TO SENDER
☐ RETAIN PREVIOUS REVISION OF THE ABOVE DOCUMENT(S) FOR YOUR RECORDS.
☐ THIS DOCUMENT IS PROPRIETARY INFORMATION.
☐ THIS DOCUMENT IS CONFIDENTIAL.

☐ OTHER

PLEASE ACKNOWLEDGE RECEIPT OF THE ABOVE DOCUMENT(S) BY SIGNING THIS TRANSMITTAL FORM AND PROMPTLY RETURNING IT TO THE ADDRESS NOTED BELOW. IF PREVIOUS REVISION OF THE DOCUMENT(S) IS TO BE DESTROYED, THE FOLLOWING SIGNATURE ALSO CERTIFIES THE DESTRUCTION OF THE DOCUMENT(S).

| | |
|---|---|
| SIGNATURE: | DATE: |

SIGNED COPY OF THIS TRANSMITTAL SHOULD BE RETURNED TO:

### 17.6.5 Project Logbooks

Site Managers who are responsible for conducting field investigations must be issued serialized logbooks. The SM is responsible for recording all pertinent project information including, but not limited to, field work documentation; field instrumentation readings; calculations; calibration records; work plan distributions; photograph references; sample tag/ label numbers; meeting information; and important times and dates of telecons, correspondences, or deliverables.

Onsite measurements and field operations are recorded in the logbooks with pertinent information necessary to explain and reconstruct sampling operations. Entries made in the log book must be dated and signed by the individual who made the entry unless entry is by the individual to whom the logbook was originally assigned. The SM or designee must sign the logbook at the close of each day; the SM may wish to review and initial each page daily.

Project logbooks are the property of the regional office and are to be turned over to the project file when a project assignment has been concluded.

As an alternative to recording detailed sampling information or instrument calibration in logbooks, separate sampling record forms may be used. However, general site information must be recorded in the logbook, and the use of such forms should be referenced in the logbook. The reader should refer also to Section 4 of this compendium.

### 17.6.6 Computer Codes and Documentation

Computer codes used for analysis, modeling, or design applications should be baselined, controlled, and documented. Documentation stored by computer system (e.g., chain-of-custody records and analysis reports) must be adequately safeguarded.

#### 17.6.6.1 Documentation, Verification and Retention of Software Programs

One person must be designated as responsible for ensuring that all computer programs, whether developed internally or acquired from an outside source, are documented in sufficient detail so that each can be understood and verified by an independent reviewer. The program documentation should contain the following:

- **Program Identification:** Give the program name, descriptive title, and information necessary to uniquely define the current version.
- **Description of Problem or Function:** Define the problem to be solved or function to be performed by the program.
- **Method of Solution:** Summarize mathematical techniques, procedures, and numerical algorithms employed for solution.
- **Related Material:** List any auxiliary programs or external data files required for implementation of this program.
- **Restrictions:** Discuss limitations imposed by the mathematical model or computer facilities.
- **Computer(s):** Identify the computer(s) on which the program has been successfully executed.

- **Programming Languages:** Indicate the languages used and approximate function of each.
- **Operating Systems:** Identify the software system and versions used.
- **Machine Requirements:** List the computer hardware required for implementation of the program.
- **Authors:** Give the names and addresses of the author(s) and the individuals currently responsible for the program.
- **References:** List directly related publications and other reference materials.
- **User's Manual:** Describe all input required for the program including input format. Include all information required for a successful computer run (e.g., special input techniques, handling of consecutive cases, default values of input parameters). Provide sample problems with control cards and physical interpretations of input and output.
- **Source:** List the source program as compiled or assembled.

### 17.6.6.2 Verification

Verification is the process of ensuring that the program performs correctly and is required for all computer programs used for quality affecting work. The extent and degree of verification will depend on the end use of the results of the analysis for which the program is employed. The extent of verification should be documented on a formal record, such as shown in Exhibit 17-4, and retained.

For programs that are widely used and accepted, verification may be limited to running originator-supplied sample problems. For other programs, verification should be accomplished by checking the mathematical modeling, numerical analysis, and computer program logic, and then by doing either of the following:

- Demonstrate that the computer program solutions to a series of test problems are in substantial agreement with those obtained by a similar, independently written program in the public domain. The program from the public domain should be a generally recognized program with sufficient history to justify its applicability and validity without further demonstration.
- Demonstrate that the program's solutions to a series of test problems are in substantial agreement with those obtained by hand calculations or from accepted experimental or analytical results published in the technical literature.

The test problems chosen for program verification should be demonstrated to be representative of the range of applicability of the problems to be analyzed by the program.

The program verification should be fully documented including methods used, details of independent calculations (manual or computer), results, and conclusions. This document must be attached to the record of computer software verification.

## Exhibit 17-4
## RECORD OF COMPUTER SOFTWARE VERIFICATION

*RECORD OF COMPUTER SOFTWARE VERIFICATION*

| | |
|---|---|
| DESCRIPTION OF VERIFICATION ACTIVITIES AND FINDINGS (CONT'D): | PAGE OF |
| VERIFIED BY: | DATE: |
| ACCEPTED BY (REGIONAL/OFFICE MANAGER): | DATE: |
| REVIEWED BY QA: | DATE: |

NUS 447 38 0183

**Exhibit 17-4**
**(continued)**

## *RECORD OF COMPUTER SOFTWARE VERIFICATION*

SOFTWARE PACKAGE NAME:

PAGE OF

DEVELOPER:

PROGRAMMER:

COMPUTER TYPE:

VERIFICATION SCOPE:

- ☐ SAMPLE PROBLEM FROM ORIGINATOR
- ☐ MATHEMATICAL MODELING
  - ☐ COMPLETE ☐ SPOT CHECK
- ☐ NUMERICAL ANALYSIS
  - ☐ COMPLETE ☐ SPOT CHECK
- ☐ DATA LIBRARIES USED
  - ☐ COMPLETE ☐ SPOT CHECK
- ☐ BENCHMARK AGAINST EXISTING PROGRAMS
- ☐ BENCHMARK AGAINST EXPERIMENTAL RESULTS
- ☐ BENCHMARK AGAINST HAND CALCULATION(S)
- ☐ VERIFICATION TESTING PROGRAM

PROGRAM USE:

- ☐ DESIGN
- ☐ CALCULATIONS
- ☐ MANAGEMENT INFORMATION
- ☐ ANALYSIS
- ☐ OTHER

DESCRIPTION OF VERIFICATION ACTIVITIES AND FINDINGS:

#### 17.6.6.3 Retention

The documentation generated for a software program should be labeled with sufficient information to uniquely identify the version of the program to which it is applicable and should be retained in the files of the project in accordance with the applicable sections of the document control procedure described herein. A master copy of the production program disk must be maintained. No changes to this disk will be made without the proper authorization. Such authorization may be granted only after the modifications have complied with the provisions of the document control procedure.

### 17.6.7 Corrections to Documentation

As previously noted, the documentation in logbooks, sample tags/ labels, custody records, and other data sheets must be filled out with black ink. None of the accountable serialized documents listed are to be destroyed or thrown away, even if they are illegible or if they contain inaccuracies that require they be replaced. The person will simply void the document, note such void in the appropriate sign-out log, and maintain voided documents in a file.

If an error is made with an entry into the project logbook, a chain-of custody form, or sample tag/ label, the individual in error will draw a single line through the error and initial the error along with the appropriate date of change. The site sampler is responsible for completing necessary reports that detail sampling errors or omissions. This procedure also applies to words or figures inserted or added to a previously recorded statement.

If a sample tag/ label is lost in shipment, if a tag/ label was never prepared for a sample(s), or if a properly tagged/ labeled sample was not transferred with a formal chain-of-custody record, a written statement is prepared by the Site Manager detailing how the sample was collected. The statement should include all pertinent information, such as field logbook entries, regarding the sample and whether the sample was in the sample collector's physical possession or in a locked compartment until hand-transferred to the laboratory. Copies of the statement are distributed to the project files.

### 17.6.8 Confidential Information

Potentially responsible party site owners or their representatives may disclose information during investigative activities with a request for confidentiality, thus making such documents exempt for public access under the Freedom of Information Act, 5 U.S.C. 9552. Only information that is specifically exempt from disclosure by other pollution control laws, (i.e., trade secret information, information compiled as investigatory records for enforcement purposes, classified information related to national security, internal rules and practices, inter-agency and intra-agency memorandums or letters, medical records and personal files, reports and data prepared in the regulation of financial institutions, and geological and geophysical data for oil and gas well owners and operators) must be handled as confidential in accordance with EPA's requests.

A separate, locked file must be maintained for the segregation and storage of all confidential and trade-secret information. Upon receipt, this information is directed to and recorded in a confidential inventory by the responsible individual. The information is then made available to authorized personnel, but only after it has been logged out. The information must be returned to the locked file at the conclusion of each working day. Confidential information may not be reproduced except upon approval by, and under the supervision of, the responsible manager. Reproduction of confidential information should be kept to an absolute minimum.

### 17.6.9 Disposition of Project Documents

Upon termination of the project, the contents of the file are processed for storage as quality assurance records.

The cognizant project manager and document custodian are responsible for disposition of all project quality assurance records as prescribed in the work plan for that project and in the applicable procedures.

The quality assurance records retained must be dispositioned as required by the EPA. Current procedures are that all Superfund contractors' files are microfiched for transmittal to the National Archives.

## 17.7 REGION-SPECIFIC VARIANCES

These procedures are applicable to activities carried out in all 10 EPA regions; however, slight variations in the application of these procedures may occur. EPA Region V has indicated the following variations. Regarding Section 17.6.1, Project Files, Region V does not use the authorized-access listing approach to limit access to files. All Region V personnel have access to files unless the files are identified as confidential. Also, Region V does not use separate file folders to segregate information. Pertaining to Section 17.6.2, Document Identification and Numbering, Region V handles field activity documents, such as sample tags and traffic reports, through a system that is independent from office file document control systems.

For Section 17.6.6, Sample Identification Documents, all unused filed sampling documents in Region V are kept by the person to whom they were assigned and maintained for future use. This information should be recorded in the sampling logbook.

Exhibit 17-1, File Inventory, is the same as Region V's Document Control Log Sheet. Because variances can become dated rapidly, the user should contact the EPA RPM for current information. All further regional variations will be incorporated in Revision 01 of this compendium.

## 17.8 INFORMATION SOURCES

Environmental Law Institute. *Duties to Report or Disclose Information on the Environmental Aspects of Business Activities.* September 1984; revised September 1985.

National Enforcement Investigations Center. *Enforcement Considerations for Evaluations of Uncontrolled Hazardous Waste Disposal Sites by Contractors.* Denver, Colorado. April 1980.

Toledo Edison Company. *Quality Assurance Program Specifications for Operations Phase Suppliers/ Contractors.* Davis-Besse Nuclear Power Station. (No date of publication.)

U.S. Department of Energy. *Quality Assurance Handbook for Geologic Investigations.* National Waste Terminal Storage Program. October 1982.

U.S. Environmental Protection Agency. *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans.* Office of Monitoring Systems and Quality Assurance, Office of Research and Development. Washington, D.C. 29 December 1980.

# SECTION 18

# CORRECTIVE ACTION

## 18.1 SCOPE AND PURPOSE

The corrective action program covers the analysis of the cause(s) of any negative audit findings and the corrective actions required. This program includes the investigation of the causes of significant or repetitious unsatisfactory conditions relating to the quality of the materials, components, or services, or the failure to implement or adhere to required quality assurance practices.

This procedure establishes the methods for implementing and documenting corrective actions.

## 18.2 DEFINITIONS

**Corrective Actions**

Those actions taken in response to nonconformance reports, audit findings, or surveillance or monitoring findings. Audit reports require some stated specific action; other reports may often be implemented as well.

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within a budget and schedule. The person is also referred to as Site Project Manager or the Project Manager, and is typically a contractor's employee (see Subsection 1.1).

## 18.3 APPLICABILITY

The corrective action procedure is applicable to those activities that affect quality control carried out at hazardouus waste site investigations and that require corrective actions.

## 18.4 RESPONSIBILITIES

The quality assurance representative is responsible for reviewing audit reports and nonconformance reports to determine the significant or repetitious conditions adverse to quality, or the failure to implement or adhere to required quality assurance practices.

When such problems are identified, the responsible manager or the designee must investigate the causes of the problems and is responsible for defining and implementing the necessary actions to correct the problems. The responsible manager must identify the person or persons responsible for initiating the actions for remedying any immediate effects of the problems.

## 18.5 RECORDS

Documentation that supports major corrective actions should be maintained in the project files and in the quality assurance files using the techniques discussed in Section 17, Document Control, of this compendium.

## 18.6 PROCEDURES

### 18.6.1 Limits for Data Acceptability

The quality of data generated by sampling, monitoring, or analyzing, is defined in terms of the following:

**Accuracy:** The degree of agreement of a measurement (or an average of measurements of the same thing), $X$, with an accepted reference or true value, $T$, usually expressed as the difference between the two values, $X\text{-}T$, or the differences as a percentage of the reference or true value, 100 $(X\text{-}T)/T$, and sometimes expressed as a ratio, $X/T$. Accuracy is a measure of the bias inherent in the system.

**Precision:** A measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions. Precision is best expressed in terms of the standard deviation. Various measures of precision exist depending on the prescribed similar conditions.

**Completeness:** A measure of the amount of the valid data obtained from a measurement system, compared with the amount that was expected to be obtained under correct normal conditions, and that was needed to be obtained in meeting the project data quality objectives.

**Representativeness:** The degree to which data accurately and precisely represent a characteristic of population, the parameter variations at a sampling point, a process condition, or an environmental condition. It also includes how well the sampling point represents the actual parameter variations that are under study.

**Comparability:** The confidence with which one data set can be compared with another; a qualitative characteristic that must be assured in terms of sampling, analysis, reporting, etc.

The exact values of these quality characteristics will vary depending on the analytical processes and procedures involved. The processes and procedures used throughout the project are based on established techniques and methods. In many cases, existing EPA standard operating procedures will be used. Where these are not available or suitable, nationally recognized procedures, such as those established by the American Society for Testing and Materials (ASTM) will be employed.

Individual work plans will detail the recommended field activity and analytical methodology to establish that these variables are adequate to support future decisions.

### 18.6.2 Control of Data Acceptability

Measures must be established and documented so that conditions adverse to quality, such as deficienciies, deviations, nonconformances, defective material services and/or equipment, can be promptly identified and corrected.

The identification of conditions adverse to quality, the cause of the condition, and the corrective action taken, must be documented and reported to appropriate levels of management.

The area of concern must be audited in a timely manner to establish that the corrective action has been accomplished.

### 18.6.3 Reviews

The results of audits must, within 30 days of receipt, be reviewed by the quality assurance representative to determine the need for corrective action beyond the corrective action in the audit report. If this audit review reveals that major or long-term corrective actions are needed, the responsible managers will obtain from their staffs a commitment to define and implement the necessary actions to correct the cause(s) of the problem, as well as to remedy any immediate effects of the problem. In addition, several time critical field events are short-term activities that must recieve immediate corrective-action attention. In other words, the deficiency must be effectively remediated well before completion of the event to ensure data acceptability.

### 18.6.4 Nonconformance

If a deficiency that affects the quality, validity, or both, of a work product is discovered after final quality verification, the project work and verification process should be reviewed for adequacy. Modifications to project work will be initiated if necessary.

### 18.6.5 Corrective Action Approval

Proposed major corrective actions shall be approved by the responsible manager. The quality assurance representative must be consulted and must concur with proposed major corrective actions.

### 18.6.6 Corrective Action Review

The quality assurance representative must review the results of major corrective actions after implementation to determine the effectiveness of the actions and report the results of this review to the program manager.

### 18.6.7 Corrective Actions for Data Acceptability

Corrective action procedures for data acceptability have been determined by EPA accepted practices and methods. Section 16, Data Reduction, Validation, and Reporting, of this compendium also contains information on corrective action procedures.

## 18.7 REGION-SPECIFIC VARIANCES

All region-specific variations to this section will be incorporated in Revision 01 of this document, because no variations were identified during the draft review. Users information on variations.

## 18.8 INFORMATION SOURCES

National Enforcement Investigations Center. *Enforcement Considerations for Evaluations of Uncontrolled Hazardous Waste Disposal Sites by Contractors*. Denver, Colorado. April 1980.

Toledo Edison Company. *Quality Assurance Program Specifications for Operations Phase Suppliers/Contractors.* Davis-Besse Nuclear Power Station. (No date of publication.)

U.S. Department of Energy. *Quality Assurance Handbook for Geologic Investigations.* National Waste Terminal Storage Program. October 1982.

U.S. Environmental Protection Agency. *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans.* Office of Monitoring Systems and Quality Assurance, Office of Research and Development. Washington, D.C.

# SECTION 19

# QUALITY ASSURANCE AUDIT PROCEDURES

## 19.1 SCOPE AND PURPOSE

Each project plan must describe the internal and external performance and systems audits that will be required to monitor the capability and performance of the total measurement system(s).

Section 19 describes the activities usually accomplished in the performance of audits. The preaudit meeting, audit performance, evaluation of audit findings, postaudit meeting and audit reporting are addressed.

## 19.2 DEFINITIONS

**Audit (Office, Field, Laboratory)**
A documented activity performed in accordance with written procedures or check lists to verify, by examination and evaluation of objective evidence, that applicable elements of the quality assurance program have been developed, documented and effectively implemented in accordance with specific requirements.

**Auditor**
A staff member who can perform audit activities under the directions of a lead auditor. Persons classified as auditors shall not serve as audit team leaders nor perform audits independently.

**External Audit**
An external audit is performed by an auditor(s) not employed by the company or organization being audited. External audits are performed to verify that a subordinate participant in a project is exercising effective controls over its responsibilities for the implementation of the overall quality assurance program.

**Internl Audit**
An internal audit is performed by an auditor(s) employed by the company or agency to which the audit activity belongs. Internal audits are performed to verify that the developments or organizations within the company are conforming with the quality assurance program.

**Lead Auditor(Audit Team Leader)**
A staff member who, by virtue of education, training and experience, can organize and direct audits, can report audit findings, and can evaluate corrective actions.

**Performance Audits**
Performance audits are normally conducted after the data production systems are operational and are generating data. Such audits independently collect measurement data by using performance evaluation samples to determine the accuracy of the total measurement system or portions thereof.

**Site Manager (SM)**
The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

**Systems Audits**

Systems audits are regularly performed and encompass all aspects of the program. For purposes of this procedure, systems audits will consist of evaluations of all components of the applicable measurement systems to determine their proper selection and use. The total data production process, which includes onsite reviews of both field and laboratory systems and facilities for sampling, calibration, and measurement protocols, is normally covered by systems audits.

**Technical Expert**

A staff member who is knowledgeable in the technical discipline being audited but is not qualified as an auditor.

## 19.3 APPLICABILITY

The audit procedure is applicable to the quality assurance audits conducted on projects dealing with Superfund hazardous waste site investigations.

## 19.4 RESPONSIBILITIES

The quality assurance representative is responsible for preparing and maintaining a schedule of audits as described in this procedure.

Qualifications and certification of the audit personnel should be reviewed and documented by the quality assurance representative.

The audit team leader is responsible for preparing an audit. These responsibilities include the selection of an audit team, preparation of an audit plan and audit checklist, special training and orientation of the audit team, and notification of the organization being audited.

The audit team leader and, where applicable, the other members of the audit team are also responsible for complying with the instructions identified in this procedure for conducting audits.

Audit follow-ups should be conducted by the audit team leader to verify that corrective action on audit findings is adequate and complete.

Documented findings identified during audits are to be completed on the quality notice form (Exhibit 19-1). The quality notice form should be completed in accordance with the procedures outlined in Exhibit 19-2 (instructions) and is the responsibility of the audit team members.

## 19.5 RECORDS

The following records are generated in support and completion of the quality assurance audits for Superfund projects:

- Audit schedules and revisions thereto
- Audit qualification records
- Certification records (current and historical)

- Audit checklists and audit guides
- Audit plan
- Audit reports
- Written response to audit reports
- Response evaluations
- Records of audit closure

## 19.6 PROCEDURES

The following procedure describes the methods used in establishing and conducting an audit. Office, field, and laboratory audits may vary in context but follow the generic guidelines of this procedure.

### 19.6.1 Audit Schedules

An audit schedule should be established for each year of the project. The schedule will include both internal and external audits, providing external audits are required.

The schedule is reviewed periodically and revised as necessary to reflect current scheduling of activities that affect quality and to provide adequate coverage of the implementation of the quality assurance program.

The frequency of audits is based on the level of participation of the audited organization in activities that affect quality.

The published schedule contains the following information:

- Name and project organization (or subcontractor or consultant) to be audited
- Subject of the audit
- Scheduled date of the audit
- Audit team leader

Audits are scheduled so that the quality assurance programs covering the activities are effective during all phases of the program.

The audit schedule is distributed to all appropriate management personnel of the offices being audited. Audit schedules prepared by the quality assurance representative for specific office activities (e.g., field audits, laboratory audits, and/or office audits) are distributed to the cognizant manager.

Quality assurance personnel may conduct unscheduled audits when one or more of the following conditions exist:

- When it is necessary to determine the capability of a supplier's quality assurance program prior to award of a subcontract
- When, after the award of a contract, sufficient time has elapsed for implementation of the quality assurance program, and when it is necessary to determine that the organization is performing in accordance with the program
- When significant changes are made to activities affecting quality, such as reorganization or major revision of quality assurance manuals, procedures, or other controlling documents
- When it is suspected that the quality of the services provided is in jeopardy because of non conformance with the quality assurance program
- When a systematic, independent assessment of the program's effectiveness is considered necessary
- When it is necessary to verify that required corrective actions have been implemented

## 19.6.2 Qualification and Certification of Quality Assurance Personnel

### 19.6.2.1 Auditor Qualification

Three categories of personnel perform audits: auditor, lead auditor and technical expert. The qualifications for these three categories are as follows:

**Auditor:** To be classified as an auditor, an individual must, as a minimum, be given specific training in the content and objectives of the quality assurance program and in audit procedures and be evaluated on knowledge of these documents.

**Lead Auditor:** To be classified as lead auditor, the individual must meet the requirements for auditors. In addition, the individual should have served as a team member in the conduct of at least two audits led by a lead auditor.

**Technical Expert:** The technical experts are not required to be qualified as auditors. They are selected on the basis of technical expertise in the area being audited and are part of an audit team led by an auditor. They are given specific training in the preparation and use of checklists and in the conduct of an audit.

### 19.6.2.2 Certification

The quality assurance representative documents the basis for auditor certification and provides written certification. The program office manager certifies the quality assurance representative. The certification must state the classification of the individual and the expiration date of the certification.

## 19.6.3 Preparation for Audits

### 19.6.3.1 Audit Team Selection

The audit team leader for internal audits is selected by the quality assurance representative. Audit team members are also selected by the quality assurance representative.

Individuals are selected for quality assurance audit team assignments on the basis of experience or training commensurate with the complexity or special nature of the activities to be audited. Any special abilities, specialized technical training, previous experience, personal characteristics, education, or physical capability that is applicable to the assignment are to be considered during selection.

### 19.6.3.2 Written Audit Plan

The audit team leader is responsible for the preparation of a written audit plan, when specifically requested by the quality assurance representative.

The audit plan includes the following information:

- Audit number
- Audited organization
- Subject of the audit
- Scope of the audit
- Projects or activities to be audited
- Names of the audit team members
- Schedule
- Applicable documents

### 19.6.3.3 Audit Checklists

The audit team leader is responsible for directing the preparation of audit checklists or an audit guide.

The following guidelines are used in preparing checklists:

**Initial Baseline Audits:** Checklists are based on quality assurance program documents (e.g., quality assurance manuals, plans, procedures, applicable standards).

**Follow-up Audits:** Checklists are based on a review and evaluation of findings from previous audits, responses to these findings, and available objective evidence of implementation of corrective action.

**Periodic Audits:** Checklists emphasize areas considered critical to the program at the time of the audit or found weak but not reported as a finding during a previous audit.

## Exhibit 19-1
## QUALITY NOTICES

*QUALITY NOTICE*

| | | | |
|---|---|---|---|
| (1) QN NO. | (2) CODE. | (3) CATEGORY:<br>☐ OFFICE ☐ SDD/TDD/WA ☐ PROGRAM | |
| (4) SOURCE.<br>☐ QA INTERNAL AUDIT ☐ QA EXTERNAL AUDIT ☐ OTHER ______ | | | |
| (5) PROJECT | | (6) AUDIT GUIDE REFERENCE | |
| (7) AUDITED ORGANIZATION | (8) ORGANIZATIONAL UNIT | (9) ACTIVITY | |
| (10) RESPONSE ASSIGNED TO | | (11) REPORTED BY | (12) DATE |
| (13)<br>☐ OBSERVATION | | (14)<br>☐ DEFICIENCY | |
| (15) REFERENCE DOCUMENT | | | |
| (16) REQUIREMENT (CITE) | | | |
| (17) DESCRIPTION | | | |
| (18) RESPONSE DUE DATE | (19) SCHEDULED REAUDIT DATE | (20) APPROVED BY | (21) DATE |
| (22) RESPONSE (TO BE COMPLETED BY AUDITED ORGANIZATION) | | | |
| TO SUBSTANTIATE COMPLETION OF CORRECTIVE ACTION. ATTACH DOCUMENTATION AS APPROPRIATE. | | (23) SUBMITTED BY | (24) DATE |
| TO BE COMPLETED BY AUDITING ORGANIZATION | | | |
| (25)<br>☐ SATISFACTORY | (26)<br>☐ UNSATISFACTORY | (27) REVIEWED BY: | (28) DATE. |
| (29)<br>☐ SATISFACTORY | (30)<br>☐ UNSATISFACTORY | (31) REAUDIT DATE | (32) REFERENCE QN NO(s) (FOR UNSATISFACTORY REAUDIT) |
| (33) REMARKS. | | (34)<br>☐ QUALITY NOTICE CLOSED | |
| | | (35) APPROVED BY: | (36) DATE. |

# Exhibit 19-2
# QUALITY NOTICE INSTRUCTIONS

The Quality Notice Form shall be used by persons performing Quality Assurance (QA) Audit or Surveillance of activities affecting the timely and effective formulation or implementation of a defined QA program. This form is applicable to all types of goods and services (hardware and software) provided in accordance with requirements of a QA Program. This form may be used by project management representatives for monitoring decisions, actions or events associated with QA programs pertinent to work performed under their jurisdiction.

The Quality Notice Form shall be used by personnel identified above to describe the condition when:

A. Specified quality for a product, process or system has been violated; i.e., a quality DEFICIENCY (audit finding) is to be documented by the observer and appropriate corrective action is to be committed for scheduled accomplishment by the audited/monitored organization, or

B. The capability of the audited/monitored organization to demonstrate with meaningful level of confidence, continued achievement of appropriate quality appears to be in jeopardy; i.e., an OBSERVATION is to be documented by the observer and is to be acted upon by the audited/monitored organization in accordance with agreement(s) established by the observer with the audited/monitored organization.

(1) Enter identifier for each Quality Notice (QN) issued. Unless prescribed otherwise, the observer shall establish identification appropriate to his needs: e.g., 01, 02.

(2) Leave blank (this space may be used for subsequent codification and quality trend analyses).

(3) Mark the box(es) which best describes the category of the reported observation or deficiency.

(4) Mark the box which describes the source of the cited observation or deficiency (see Note 1 below).

(5) Enter identification (e.g., name or number) of project under which activity was performed.

(6) Enter identification of guide used to isolate and identify the observation or deficiency, e.g., audit checklist, detailed scope of work, memorandum, action item report, tickler file, etc.

(7) Enter name and location of organization subjected to audit/surveillance/monitoring action.

(8) Enter name of department or section where the noted observation or deficiency occurred.

(9) Identify the specific task, action or work assignment undergoing audit/surveillance/monitoring when the observation or deficiency was isolated and identified: e.g., performing magnetic particle inspection of containment vessel welds (hardware); reducing strip chart data for wind speed and wind direction (software).

(10) Enter the name of the audited/monitored organization representative responsible for providing observation or deficiency responses.

(11) Enter the observer's name.

(12) Record the date on which the observation or deficiency was documented.

(13) Mark this box when quality is in jeopardy as described above in Instruction B (see Note 2 below).

(14) Mark this box when quality is violated as described above in Instruction A (see Note 2 below).

(15) A. When item (13) is marked, enter the name and identification of applicable document(s) containing the specific quality requirements that should be implemented to prevent or to mitigate the conditions adverse to quality.

B. When item (14) is marked, enter the name and identification of document(s) containing the specific quality requirements violated.

(16) A. When item (13) has been marked, enter (excerpt if available) specific quality requirements that should be implemented to prevent or to mitigate the conditions adverse to quality.

B. When item (14) is marked, enter excerpt from specific quality requirement violated.

(17) Record in terse concise language a description of the observation or deficiency.

(18) Record the due date of the response from the audited/monitored organization.

(19) Record the next scheduled date for audit/surveillance/monitoring action to assess observation or deficiency corrective progress. When the exact date of the assessment can not be determined, enter "TBD" (to be determined). Enter N/A (not applicable) when assessment will not be made.

(20) Enter name of person authorized to approve the QN. Unless prescribed otherwise, this will be the audit team leader or the observer (see item 11).

(21) Record date QN was approved for transmittal to the audited/monitored organization.

(22) Record in detail the total response. To be satisfactory it must:

A. Dispose of any affected product, results, or paperwork.

B. Correct the situation that caused the QN to be issued.

C. Provide a mechanism to prevent recurrence.

D. Identify who shall do the above and,

E. When it shall be accomplished.

(23) Enter name of person in the audited/monitored organization who has submitted the response.

(24) Record the date that the response was submitted.

(25)(26) Mark the box that describes the response.

(27) Enter the name of the person who reviewed the response.

(28) Record the date the response was reviewed.

(29)(30) When an on-site assessment of the observation or deficiency is made, mark the box that describes the interim action by the audited/monitored organization. Enter N/A when an on-site assessment will not be made.

(31) Record the date the on-site assessment was made. No assessment, mark the block N/A.

(32) Record all QN numbers documenting assessment of the original observation or deficiency. No assessment, mark the block N/A.

(33) Enter comments pertinent to NUS evaluation of corrective action or conditions for closing the QN, otherwise enter N/A.

(34) When conditions are appropriate, mark the box to close the QN.

(35) Enter the name of the person who approved closing the QN.

(36) Record the date the QN was closed.

**Note 1:** QN's initiated by other than QA personnel are to be immediately sent to QA for action.

**Note 2:** Items (13) and (14) are mutually exclusive; i.e., the observer must choose and mark only one of these two boxes.

#### 19.6.3.4 Audit Team Orientation

The team leader prepares the team prior to initiation of the audit and assigns specific areas for each member to audit in accordance with checklists the team has prepared. Pertinent policies, procedures, standards, instructions, manuals plans, codes, regulatory requirements, prior audit reports, and responses should be made available to the team for information and review. Also, each auditor is provided with copies of the audit plan, procedures, and checklists necessary to ensure an orderly audit. The team leader established that the auditors understand the internal and external organization and contractual interfaces and responsibilities of the organization to be audited.

### 19.6.4 Conduct of Audits

#### 19.6.4.1 Audit Meeting

Upon arrival at the audit site, the audit team leader conducts a meeting with the audit team members and cognizant management of the organization to be audited.

The following are purposes of the preaudit meeting:

- Introduce auditors
- Meet counterparts
- Confirm the scope of the audit
- Present the audit plan
- Discuss the audit sequence
- Establish channels of communication
- Schedule a postaudit meeting

#### 19.6.4.2 Audit Performance

The audit team leader prepares audit checklists or audit guides. The depth and scope of the audit are determined and incorporated into the checklists or guides. The audit team leader establishes the ground rules for the audit and assigns to the various team members the specific areas each is to cover in the audit.

The audit checklists and guides are used to guide the audit and to provide adequate depth, scope, and continuity. However, the audit is not restricted to the checklists when evidence raises questions not specifically addressed in the checklists. The audit activity includes the review of objective evidence to verify adequate implementation of the quality assurance program.

Audit team members record each finding (observation or deficiency) on a formal record such as a quality notice form (Exhibit 19-1). This form is prepared in accordance with the information contained in this section. When a finding is identified, sufficient investigations should be conducted to determine the basic cause of the finding.

The quality notice form is used to document the findings of internal audit activities and the resolution of the findings. Findings can be categorized as follows:

- **Category A (Deficiency):** Recognition of a specific requirement (e.g., program, procedure, process) that has been violated.
- **Category B (Observation):** Recognition of an activity or action that might be improved but is not in violation of a specific requirement. Left alone, the activity or action may develop into a deficiency (Category A).

The processing of the quality notice form is outlined in Subsection 19.6.5, Audit Follow-Up.

Deficiencies are written only when there is a clear violation of a specific quality assurance requirement.

Any identified findings that require immediate corrective action are reported immediately to the management of the audited organization and recorded on a quality notice form. For internal audits, the quality assurance representative is notified immediately.

#### 19.6.4.3 Evaluation of Audit Findings

Members of the audit team draft their own findings on quality notice forms. These drafts are reviewed by the audit team leader. Findings are stated in clear, concise statements of facts that identify the problem.

#### 19.6.4.4 Postaudit Meeting

At the conclusion of the audit, a postaudit meeting is conducted. The meeting is chaired by the audit team leader. Those in attendance should include members of the audited organization who can verify the validity of the findings and members of management who can correct the problems identified by the audit.

The objectives of the postaudit meeting are to:

- Discuss the audit findings
- Determine and resolve any errors or misunderstandings regarding the findings
- Achieve agreement of the validity of the findings and on those findings that constitute noncompliance.
- Recommend improvements or corrective actions to the audited organization
- Establish a tentative plan and schedule for the development and implementation of the corrective actions
- Schedule a follow-up audit, if appropriate

#### 19.6.4.5 Audit Reporting

The audit team leader is responsible for preparation of the audit report, which provides the following:

- Description of the audit scope
- Identification of the audit team
- Identification of persons contacted
- A summary of the audit findings
- Any agreements and/or recommendations for correcting deficiencies or for improving the quality assurance program, as appropriate

The report or transmittal letter must require response by the audited organization. The distribution of audit reports for internal audits includes the cognizant project managers, the quality assurance representative, and the management of the audited organization. The report is usually issued within 30 days after the audit is completed.

#### 19.6.4.6 Audit Response

The manager of the audited organization is requested to respond to the audit report within 30 days of receipt. The response relates the corrective action taken or outlines the plan and schedule for corrective action. In the case of long-term corrective action, periodic progress reports are submitted by the manager of the audited organization to the lead auditor, the quality assurance representative and the appropriate manager.

### 19.6.5 Audit Follow-Up

#### 19.6.5.1 Audit Response

The program office manager takes, in a timely manner, those actions necessary to correct the deficiencies identified during the audit.

#### 19.6.5.2 Audit Follow-Up

The audit team leader follows up all open findings in audit reports, receives audit report responses, and evaluates the responses to determine that the corrective action for each finding has been adequately completed or scheduled.

The audit team leader may accomplish follow-up as required through written communication, reaudit, or other appropriate means.

The audit team leader informs the audited organization in writing of any unsatisfactory response, indicates why the response is considered unsatisfactory, and specifies a reply due date. The quality assurance representative is informed of unsatisfactory responses by copy of the written notification.

### 19.6.5.3 Audit Finding Closure

Each audit finding is considered open until a satisfactory written reply (e.g., report follow-up response) has been received from the audited organization documenting that corrective action has been completed.

Only the audit team leader or, in the case of unavailability, the designee can close an audit finding. This individual indicates the closure by signing and dating the quality notice form.

All closed quality notice forms are retained as quality assurance records.

## 19.7 REGION-SPECIFIC VARIANCES

This procedure is applicable to all contractor, regional EPA, and state personnel who conduct hazardous waste investigations. Slight variations in the application of the project file numbers, control methods of accountable documents, or use of a transmittal letter rather than a document transmittal form may occur. However, these variations can occur only after a suitable alternative method for these control mechanisms has been reviewed, approved, and documented by the responsible RPM. The user should contact the EPA RPM for up-to-date information on variances. Future variances will be included in Revision 01 of this compendium.

## 19.8 INFORMATION SOURCES

National Enforcement Investigations Center. *Enforcement Considerations for Evaluations of Uncontrolled Hazardous Waste Disposal Sites by Contractors.* Denver, Colorado. April 1980.

Toledo Edison Company. *Quality Assurance Program Specifications for Operations Phase Suppliers/Contractors.* Davis-Besse Nuclear Power Station. (No date of publication.)

U.S. Department of Energy. *Quality Assurance Handbook for Geologic Investigations.* National Waste Terminal Storage Program. October 1982.

U.S. Environmental Protection Agency. *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans.* Office of Monitoring Systems and Quality Assurance, Office of Research and Development. Washington, D.C. 29 December 1980.

# SECTION 20

# QUALITY ASSURANCE REPORTING

## 20.1 SCOPE AND PURPOSE

On a periodic basis, usually monthly, quality assurance (QA) reports should be issued to the appropriate Project Manager and, as appropriate, to the responsible higher management. These reports summarize the quality assurance and quality control status of the project and any conditions adverse to quality. The QA reports address the assessment of measurement data accuracy, precision and completeness, results of any performance audits, results of system audits, any reported nonconformances, and any significant quality assurance problems, together with recommended solutions, and any new quality assurance and quality control processes as dictated by the client.

## 20.2 DEFINITIONS

**Report**

A document that gives information for record purposes.

**Site Manager (SM)**

The individual responsible for the successful completion of a work assignment within budget and schedule. The person is also referred to as the Site Project Manager or the Project Manager and is typically a contractor's employee (see Subsection 1.1).

## 20.3 APPLICABILITY

This reporting procedure is applicable to the QA tasks associated with Superfund remedial response activities.

## 20.4 RESPONSIBILITIES

The QA representative is responsible for providing to management the periodic reports on performance of measurement systems and data quality for the respective projects.

## 20.5 RECORDS

The records to be generated in compliance with this procedure are the monthly QA reports.

## 20.6 PROCEDURES

The following subsection describes the parameters used in assessing the quality assurance and quality control (QA/QC) status of project activities and the means of reporting such assessments.

### 20.6.1 Assessment of Measurement Data Accuracy

The routine procedures used for assessing the precision, accuracy, and completeness of measurement and monitoring data should be evaluated and reviewed for compliance with nationally recognized practices and with regionally approved and documented procedures. This review should include, but not be limited to, assessment of the completeness of work plans and their reference documentation of field data collection and analytical guidelines, calibration and standardization procedures, measurement and monitoring equipment maintenance and repair records, and personnel qualification records, as well as assessment of documentation provided by field and laboratory logbooks and data sheets. Such assessments, favorable or unfavorable, should be identified in the QA report.

### 20.6.2 Assessment of Performance and Systems Audits

Quality assurance performance and system audits are routinely conducted, in accordance with Section 19, Quality Assurance Audit Procedures, to determine the effectiveness of the quality assurance program and implementation. A summary of findings or observations resulting from the audits is assessed and reported to the responsible manager. The summary includes a brief description of the organization or section(s) being audited, responsible personnel, dates of audit activities, and particular type of audit (internal or external), as well as, a concise description of particular activity findings and recommended actions to be taken to clear up such findings.

### 20.6.3 Nonconformances

The QA representative reports any nonconformances that may have occurred during the course of project activities. Nonconformances may occur as a result of an identified or suspected deficiency in an approved document (e.g., technical report, analysis, calculations, or computer program) or an activity that is not conducted in accordance with the established plans or procedures. The reported nonconformances are also accompanied by a brief description of the activity or activities to be performed to clear up the nonconformances.

### 20.6.4 Assessment of Quality Assurance Problems and Solutions

A section of the QA report is devoted to identifying any problems, solutions, or accomplishments of the overall quality assurance program. This section analyzes the general QA/QC status of the program and identifies any satisfactory or unsatisfactory trends in the implementation of the program.

Any problems in the program or problems in the implementation of the program must be detailed clearly and documented along with the appropriate and complete actions needed to solve the problem.

Any new QA program development or any unusual QA project activities should also be documented in this section.

## 20.7 REGION-SPECIFIC VARIANCES

EPA Region VI requires the submittal of a final QA report for each project. The final report must be complete enough to evaluate the objectives for data quality, the audits, the laboratory data, and so on. It should include method validation and sampling designs. The user should contact the EPA RPM for up-to-date information on variances. Future regional variations will be identified and incorporated in Revision 01 of this compendium.

## 20.8 INFORMATION SOURCES

National Enforcement Investigations Center. *Enforcement Considerations for Evaluations of Uncontrolled Hazardous Waste Disposal Sites by Contractors*. Denver, Colorado. April 1980.

Toledo Edison Company. *Quality Assurance Program Specifications for Operations Phase Suppliers/Contractors*. Davis-Besse Nuclear Power Station. (No date of publication.)

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